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Wetlands Research Program Technical Report WRP-DE-11

A Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands

by Mark M. Brinson, F. Richard Hauer, Lyndon C. Lee, Wade L. Nutter, Richard D. Rheinhardt, R. Daniel Smith, Dennis Whigham

November 1995 – Operational Draft

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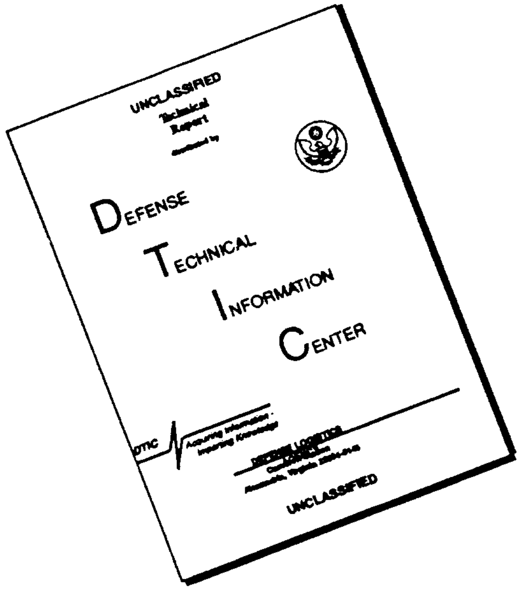

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	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

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A Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands

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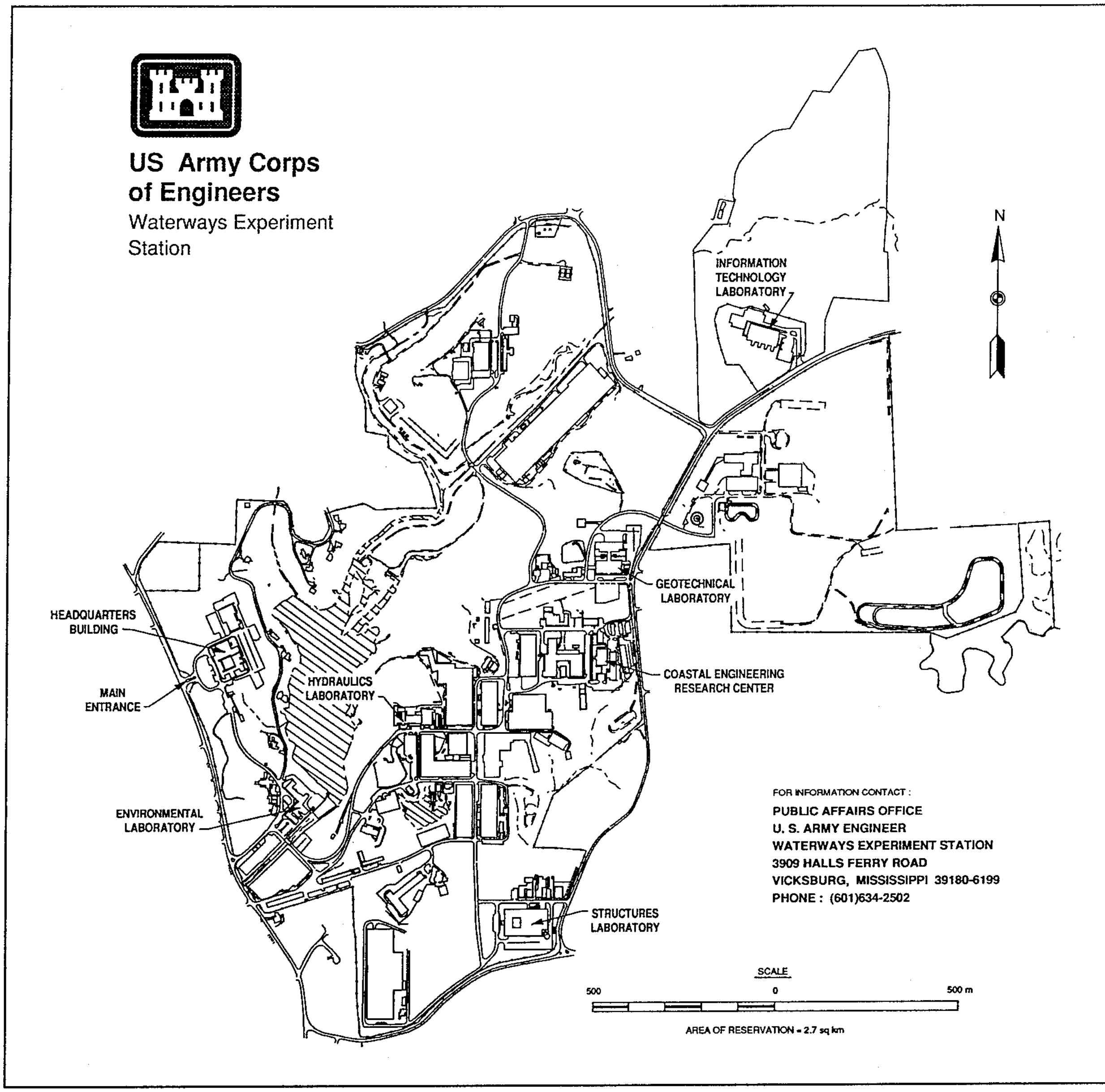

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Corps of Engineers Research Report Summary, November 1995

Assessing Wetland Functions

A Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands (WRP-DE-11)

ISSUE:

Section 404 of the Clean Water Act directs the U.S. Army Corps of Engineers to administer a regulatory program for permitting the discharge of dredged or fill material in "waters of the United States." As part of the permit review process, the impact of the discharge of dredged or fill material on wetland functions must be assessed. Existing procedures for assessing wetland functions fail to meet the technical and programmatic requirements of the 404 Regulatory Program.

RESEARCH:

The objective of this research is to develop an approach for assessing the functions of wetlands in the context of the 404 Regulatory Program.

SUMMARY:

This document is for use by a team of individuals who adapt information in this guidebook to riverine wetlands in specific physiographic regions. By adapting from the generalities of the riverine class to specific regional riverine subclasses, such as high-gradient streams of the glaciated northeastern United States, the procedure can be made responsive to the specific conditions found there. For example, separation of high-gradient from low-gradient streams may be necessary to reduce the amount of variation in indicators to make the assessment more sensitive to detecting impacts.

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Contents

Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Delineation and Evaluation Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32756, "Evaluation of Wetland Functions and Values," for which Mr. R. Daniel Smith, Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), was the Principal Investigator. Mr. John Bellinger (CECW-PO) was the WRP Technical Monitor for this work. Development funds were also contributed by the institutions, agencies, and firms with which the authors are associated (the Environmental Protection Agency (3-BO978NTEX) and the Divisions of Coastal Management (F3078) and Environmental Management (J-3054) of the North Carolina Department of Environment, Health, and Natural Resources), as well as other sources of funds and support.

Mr. Dave Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, WES, was the Wetlands Program Manager; and Mr. Ellis J. Clairain, WES, was the Task Area Manager. The work was performed under the direct supervision of Mr. Smith and under the general supervision of Mr. Clairain, Acting Chief, Wetlands Branch; Dr. Conrad J. Kirby, Chief, Ecological Research Division; and Dr. John W. Keeley, Director, EL.

This report was prepared by Dr. Mark M. Brinson, professor, Biology Department, and Dr. Richard D. Rheinhardt, research assistant, East Carolina University, Greenville, NC; Dr. F. Richard Hauer, professor, Flathead Lake Biological Station, University of Montana, Polson, MT; Dr. Lyndon C. Lee, L. C. Lee and Associates, Inc., Seattle, WA; Dr. Wade L. Nutter, hydrologist, School of Forest Resources, University of Georgia, Athens, GA; Mr. R. Daniel Smith, ecologist, WES; and Dr. Dennis Whigham, wetland scientist, Crofton, MD.

The authors wish to thank several individuals who were involved in the development of this manuscript. Mr. Richard Novitzki took part in all of the field trips and many of the discussions. His expertise in hydrology of wetlands, experience with EMAP-wetland projects, and clarity of thinking were important to the development of concepts. Mr. William Ainslie provided frequent doses of regulatory reality at critical moments and contributed through his experience in applying early versions of the method to wetlands in Kentucky. Appreciation is also expressed to Messrs. Garrett Hollands and Dennis Magee for their leadership in the field in New England and participation in meetings. Dr. Robert Beschta provided leadership in the early stages on geomorphic processes and hydrology, particularly in the western and arid regions. Dr. Gregory Auble contributed to early meetings and suggestions on subsequent drafts, and Dr. James Gosselink participated in work on the Pearl River. Dr. Ed Maltby provided perspective by keeping the Riverine Working Group abreast of parallel efforts in Europe as well as co-chairing a session at the Columbus INTECOL meeting in 1992 on functional assessment. Ms. Marie Sullivan, Dr. Julie Stromberg, and Dr. Duncan Patten guided the Riverine Working Group through the arid riparian ecosystem of Arizona. Thanks go also to Dr. Mark LaSalle for his efforts to facilitate funding during the early phase.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
square feet	0.09290304	square meters

1 Introduction

Riverine Wetlands Defined

This guidebook provides the basis for applying the hydrogeomorphic (HGM) approach for wetland functional assessment to riverine wetlands. "Riverine" refers to a class of wetland that has a floodplain or riparian geomorphic setting (Brinson 1993a). The other classes or geomorphic settings are depressional, slope, mineral soil and organic soil flats, and estuarine and lacustrine fringe (Table 1).

Table 1
Hydrogeomorphic Classes of Wetlands Showing Associated Dominant Water Sources, Hydrodynamics, and Examples of Subclasses

			Examples of Subclasses	
Hydrogeomorphic Class	**Dominant Water Source**	**Dominant Hydrodynamics**	**Eastern USA**	**Western USA and Alaska**
Riverine	Overbank flow from channel	Unidirectional, horizontal	Bottomland hardwood forests	Riparian forested wetlands
Depressional	Return flow from groundwater and interflow	Vertical	Prairie pothole marshes	California vernal pools
Slope	Return flow from groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Mineral soil flats	Precipitation	Vertical	Wet pine flatwoods	Large playas
Organic soil flats	Precipitation	Vertical	Peat bogs; portions of Everglades	Peat bogs
Estuarine fringe	Overbank flow from estuary	Bidirectional, horizontal	Chesapeake Bay marshes	San Francisco Bay marshes
Lacustrine fringe	Overbank flow from lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake marshes

Riverine wetlands occur in floodplains and riparian corridors in association with stream channels (Table 1). Dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional water sources may be interflow and return flow from adjacent uplands, occasional overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. At their headwater-most extension, riverine wetlands often are replaced by slope or depressional wetlands where channel (bed) and bank disappear, or they may intergrade with poorly drained flats or uplands. (Definitions of other classes are given in Table 2.) Riverine wetlands lose surface water by flow returning to the channel after flooding and saturation surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evapotranspiration. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long durations of saturation from groundwater sources. Bottomland hardwood floodplains are a common example of riverine wetlands.

First-order streams, usually designated by solid blue lines on U.S. Geological Survey (USGS) 7.5-min topographic maps (scale 1:24,000), are normally associated with riverine wetlands. They may also continue farther upstream where broken blue lines on topographic maps indicate the presence of channels. Perennial flow is not a requirement for a wetland to be classified as riverine.

The downstream extent of riverine wetlands is where they normally intergrade with estuarine fringe wetlands. According to the hydrogeomorphic classification, the riverine class is dominated by unidirectional flows (Brinson 1993a). The interface with the estuarine fringe class occurs where hydrodynamics change to bidirectional flows where freshwater tidal marshes and swamps can be found (Odum et al. 1984). This is an unstable transition zone for vegetation because freshwater tidal marshes and freshwater tidal swamps can be found to occur in virtually the same hydrologic and salinity regime. Plant community physiognomy strongly influences ecological functions related to habitat. Because riverine wetlands are usually forested, their vegetation is more similar to freshwater tidal swamps than to freshwater tidal marshes. Salinity strongly affects plant physiognomy, normally excluding arboreal vegetation in the range of 1 to 5 parts per thousand and higher (Brinson, Bradshaw, and Jones 1985; Conner and Askew 1992).

Riverine wetlands normally extend perpendicular from stream channel to the edge of the stream's floodplain. Large floodplains in landscapes with great topographic relief and steep hydrostatic gradients may function hydrologically more like slope wetlands because of dominance by groundwater sources. In headwater streams where floodplains are lacking or only weakly developed, slope wetlands may lie adjacent to the stream channel. Large riverine wetlands may themselves contain sites with affinities to other classes.

Table 2
Definitions of Hydrogeomorphic Wetland Classes Other than Riverine

Hydrogeomorphic Class	Definition
Depressional	Depressional wetlands occur in topographic depressions. Dominant water sources are precipitation, groundwater discharge, and both interflow and overland flow from adjacent uplands. The direction of flow is normally from the surrounding uplands toward the center of the depression. Elevation contours are closed, thus allowing the accumulation of surface water. Depressional wetlands may have any combination of inlets and outlets or lack them completely. Dominant hydrodynamics are vertical fluctuations, primarily seasonal. Depressional wetlands may lose water through intermittent or perennial drainage from an outlet, by evapotranspiration and, if they are not receiving groundwater discharge, may slowly contribute to groundwater. Peat deposits may develop in depressional wetlands. Prairie potholes are a common example of depressional wetlands.
Slope	Slope wetlands normally are found where there is a discharge of groundwater to the land surface. They normally occur on sloping land; elevation gradients may range from steep hillsides to slight slopes. Slope wetlands are usually incapable of depressional storage because they lack the necessary closed contours. Principal water sources are usually groundwater return flow and interflow from surrounding uplands as well as precipitation. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturation subsurface and surface flows and by evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. Fens are a common example of slope wetlands.
Mineral Soil Flats	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces where the main source of water is precipitation. They receive no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, saturation overland flow, and seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage, often due to spodic horizons and hardpans, and low lateral drainage, usually due to low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become the class organic soil flats. Pine flatwoods with hydric soils are a common example of mineral soil flat wetlands.
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats, in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by saturation overland flow and seepage to underlying groundwater. Raised bogs share many of these characteristics, but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are common examples of organic soil flat wetlands.

(Continued)

Table 2 (Concluded)	
Hydrogeomorphic Class	**Definition**
Estuarine Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal currents diminish and riverflow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine classes is where bidirectional flows from tides dominate over unidirectional ones controlled by floodplain slope of riverine wetlands. Because tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by saturated overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. *Spartina alterniflora* salt marshes are a common example of estuarine fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. In some cases, these wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional, usually controlled by water-level fluctuations such as seiches in the adjoining lake. Lacustrine fringe wetlands are indistinguishable from depressional wetlands where the size of the lake becomes so small relative to fringe wetlands that the lake is incapable of stabilizing water tables. Lacustrine wetlands lose water by flow returning to the lake after flooding, by saturation surface flow, and by evapotranspiration. Organic matter normally accumulates in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are a common example of lacustrine fringe wetlands.

For example, oxbow features in floodplains may assume depressional characteristics for most of the year.

Classification is made difficult not only because of these problems of scale, but also because of the continuous nature of water sources between extremes in wetland class (Figure 1).

Riverine wetlands, as applied in the HGM classifications and assessment approach, differ from the riverine class of Cowardin et al. (1979) used for National Wetland Inventory maps of the U.S. Fish and Wildlife Service (FWS). The FWS definition includes only the riverbed, bank to bank; most portions of floodplain wetlands are classified as palustrine in the FWS classification. The HGM approach classifies these areas as riverine. Rivers and floodplains in the HGM approach are assumed to be integral parts of the riverine wetland ecosystem. For practical reasons, however, the two may have to be separated for the purpose of functional assessment.

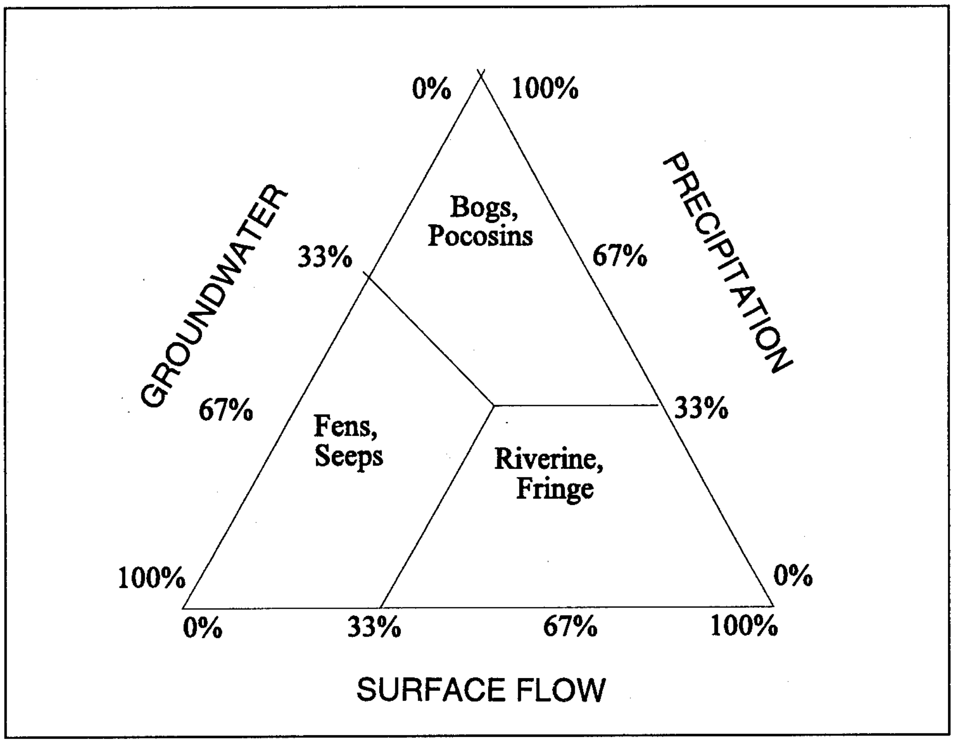


Figure 1. Diagram expressing the relative contribution of three water sources: precipitation, groundwater discharge, and surface flow. Location of major wetland classes (bogs, riverine, etc.) within the triangle shows the relative importance of water sources. Boundaries drawn between classes should not be interpreted as distinct; rather, gradients between classes are continuous (Brinson 1993b)

Purpose of the Guidebook

This document is for use by a team of individuals who adapt information in this guidebook to riverine wetlands in specific physiographic regions. By adapting from the generalities of the riverine class to specific regional riverine subclasses, such as high-gradient streams of the glaciated northeastern United States, the procedure can be made responsive to the specific conditions found in one's region of interest. For example, it may by necessary to separate wetlands associated with high-gradient streams from those associated with low-gradient streams in order to reduce the amount of variation in indicators and to make the assessment more sensitive to detecting impacts.

This guidebook is not called an assessment manual because "manual" connotes a procedure that can be taken to the field and immediately applied. The guidebook is not for direct application by environmental consultants, agency personnel, and others who assess wetland functions. For the guidebook to be useful, it must first be modified, calibrated, and tested to determine its effectiveness under local and regional conditions. Reference wetlands serve as the foundation for identifying functions, and for determining which variables and indicators are appropriate for a particular region.

The process of adapting this guidebook to regional subclasses of wetlands normally requires a team effort. Ideally, this group should consist of individuals from relevant disciplines, who are knowledgeable in hydrology, geomorphology, plant ecology, ecosystem ecology, population ecology, soil science, wildlife biology, and other related disciplines. For a regionalized procedure to be acceptable to the regulatory community, the team should include federal and state regulators, private consultants, academics, and others. This group may be called the Assessment Procedure Development Team, or simply, "A-team." Because the work of the A-team is critical in regionalizing the procedure, the team must also set standards applicable to the region so there is consistency of use over time.

One of the responsibilities of an A-team is to consistently identify and define the regional nomenclature of reference (Smith et al., in press). This task requires the talents of individuals who are very familiar with all wetland subclasses in their region, a number of individual wetland sites in each subclass, and the technical literature pertaining to each class nationally and to each regional subclass. Ultimately, the A-team must determine two critical issues that relate to the nomenclature. One is the geographic boundaries of the reference domain for each of the regional subclasses. The other is the reference standards or the level of functioning by wetlands that have the highest suite of functions (that is, the least degraded) in the reference domain (defined in Table 3). Such an effort requires a high level of knowledge about wetlands of a particular region, as well as quantitative data on reference wetlands that can be used to distinguish between wetlands used to establish reference standards and wetlands that fall short of the highest level of functioning due to alteration and other disturbances (Brinson and Rheinhardt, in press). The assessment approach document (Smith et al., in press) provides the rationale for the role of reference wetlands in functional assessment, and also provides detailed instructions for identifying reference wetlands and determining reference standards.

An A-team should keep in mind the various uses of reference in making its decision about reference domain and reference standards. Foremost is the use of reference standards as a basis for comparison with sites proposed for Section 404 projects. Not only is it necessary to distinguish between sites that meet reference standards (that is, fully functional wetlands) and those that function at some lower level, but one must also be able to measure the amount of function that will be lost following a given project. For projects that completely displace a wetland, losses in functioning are complete also and are not difficult to determine. For projects with minor impacts, the small changes are more difficult to detect and would require fine calibrations of functions. A-team members should include in their group of reference wetlands some sites below the reference standard that will help to establish potential variation for the reference domain.

Table 3
Categories and Nomenclature for Reference

Term	Definition
Reference domain	All wetlands within a defined geographic region that belong to a single hydrogeomorphic subclass.
Reference wetlands	Wetland sites within the reference domain that encompass the known variation of the subclass. They are used to establish the range of functioning within the subclass. Reference wetlands may include former wetland sites for which restoration to wetland is possible, and characteristics of sites derived from historic records or published data.
Reference standard sites	The sites within a reference wetland data set from which reference standards are developed. Among all reference wetlands, reference standard sites are judged by an interdisciplinary team to have the highest level of functioning.
Reference standards	Conditions exhibited by a group of reference wetlands that correspond to the highest level of functioning (highest sustainable capacity) across the suite of functions of the subclass. By definition, reference standard functions receive an index score of 1.0.
Site potential	The highest level of functioning possible given local constraints of disturbance history, land use, or other factors. Site potential may be equal to or less than levels of functioning established by reference standards.
Project target	The level of functioning identified or negotiated for a restoration or creation project. The project target must be based on reference standards and/or site potential and must be consistent with restoration or creation goals. Project targets are used to evaluate whether a project is developing toward reference standards and/or site potential.
Project standards	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should include and specify reasonable contingency measures if the project target is not being achieved.

If a Section 404 permit is granted, and is conditioned with compensatory mitigation requirements, reference standards represent the standard against which restoration or creation efforts are measured. Creation of riverine wetlands is difficult because rivers are highly integrated into existing landforms. Geomorphic features in particular may have required millennia to develop. Consequently, compensatory mitigation for degradation of riverine wetland functions seldom can be accomplished by creating new ones given the scarcity of appropriate sites. Opportunities for restoration, however, are normally more abundant. There are riverine wetlands in most regions of the country that exist in a degraded condition from such alterations as channelization, drainage, levees that block overbank flow, grazing, and other hydrologic alterations. Impediments to restoration, if they exist, may be due more to the lack of commitment and creative approaches to restoration or the lack of data required to detect differences in functioning than to a scarcity of sites for restoration. This situation, however, underscores the need for A-teams to construct a sensitive method for assessing function, comparing alternatives, and designing restoration strategies.

Documentation of Functions for the Riverine Wetland Class

The 15 functions identified for the riverine wetland class arose from workshops and field trips conducted by the authors and other participants (Table 4). Wetland sites were studied in the following geographic regions: glaciated New England (several streams in Massachusetts), the Gulf Coastal Plain of Mississippi (Pearl River in Mississippi), the arid Southwest (Verde, Santa Cruz, Gila, and San Pedro Rivers in Arizona), northern Rocky Mountains (Flathead River in Montana), and the Olympic Peninsula (Hoh and Queets Rivers) and Puget Sound lowlands. The process benefited also from personal experiences of the authors and participants in other regions of the United States.

Table 4
Functions of Riverine Wetland Classes Listed by Four Major Categories

Hydrologic
Dynamic Surface Water Storage
Long-Term Surface Water Storage
Energy Dissipation
Subsurface Storage of Water
Moderation of Groundwater Flow or Discharge
Biogeochemical
Nutrient Cycling
Removal of Imported Elements and Compounds
Retention of Particulates
Organic Carbon Export
Plant Habitat
Maintain Characteristic Plant Communities
Maintain Characteristic Detrital Biomass
Animal Habitat
Maintain Spatial Structure of Habitat
Maintain Interspersion and Connectivity
Maintain Distribution and Abundance of Invertebrates
Maintain Distribution and Abundance of Vertebrates

Note: Definitions are given in Appendix A.

The remainder of this chapter describes the content and introduces the sequence that is used in Chapter 2 for each of the 15 functions. The sequence is as follows: definition of function, discussion of function and rationale, description of variables and function, index of function, and documentation of functions. The function Organic Carbon Export will be used to illustrate the sequence. Upon finishing this chapter, the reader should be familiar enough with the functions and their derivation to be able to understand the rationale, assumptions, and limitations of establishing functions, and how the information on functions might be adapted to specific riverine wetland conditions. This is the material that the A-team modifies and adapts to its regional or local group of riverine subclasses. The documentation section represents the control point for updating and changing the assessment of regional subclasses.

Definition of function

A succinct definition is provided in one or a few sentences. For the function Organic Carbon Export, the definition is "export of dissolved and particulate organic carbon from a wetland. Mechanisms include leaching, flushing, displacement, and erosion."

Discussion of function and rationale

Each function is described and a brief rationale is provided, including appropriate literature citations, if available. The rationale for the choice of functions is explained in Brinson (1993a), Brinson et al. (1994), and Smith et al. (in press).

Description of variables and functions

Variables are factors that are necessary for functions to occur. For example, the Organic Carbon Export function requires a source of organic matter in the wetland and appropriate water flows to transport the organic matter downstream. The flow pathway variables for riverine wetlands include the frequency of overbank flow from the channel (V_{FREQ}), which is assumed to flood the riverine wetland surface, flow from subsurface flow (V_{SUBIN}) and surface flow (V_{SURFIN}), and surface hydraulic connections ($V_{SURFCON}$) with the stream channel. The source of organic matter (V_{ORGAN}) is defined as the types and amounts of organic matter in the wetland including leaf litter, coarse woody debris (down and standing), live woody vegetation, live and dead herbaceous plants, organic-rich mineral soils, and histosols.

To determine an index for the level of functioning (Index of Function or Functional Capacity) (Smith et al., in press), pertinent variables are combined in equations or models. The reference standards represent the highest level of sustainable functioning in the landscape. These are the conditions used to calibrate the models so that both variables and the Index of Function are set at 1.0. The equation for Organic Carbon Export is

$$Index\ of\ Function = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN} + V_{SURFCON})/4] \times V_{ORGAN}\}^{1/2}$$

If $V_{ORGAN} = 0$, the function is absent.

The equation that models the Organic Carbon Export function is arranged so the geometric mean of the last variable and the arithmetic mean of the first four can result in the Index of Function being zero if either all hydrologic variables are absent or organic matter is missing from the wetland being assessed.

Variables cannot always be quantified in absolute units in rapid assessment procedures. At a minimum, they must be measured in units that can be related to those used for reference standards developed on reference standard sites (that is, the least degraded conditions for the subclass in the reference domain). Let us assume for simplicity that biomass of trees was the only component of organic matter, V_{ORGAN}. A measurement or indicator of that component in forests is basal area. The level of the variable would be calculated based on the basal area of the forest stand being assessed relative to reference standards. Thus, a basal area of 120 ft^2/acre[1] for the site being assessed would have an index of 0.60 (120/200) relative to the reference standard of 200 ft^2/acre.

Often field indicators are not so easy to measure, either because the methods are costly and time consuming or the accuracy necessary for adequate measurement would require more effort than is warranted in rapid assessment. The cost to determine Organic Carbon Export, for example, would require monitoring of organic carbon concentrations and discharges for inflow and outflow pathways over several seasons to obtain an estimate of the function. This is simply not practical. For such costly and time-consuming methods, indicators must be used as surrogate measures for variables. In the Organic Carbon Export function, these surrogates are the presence of organic matter in the wetland and the presence of flows to transport organic matter. The justification for the use of such indicators may be mere common sense or a combination of research results and an extension of logic. For example, variable $V_{SURFCON}$ in Organic Carbon Export is "surface hydraulic connections among main and side channels." Until such time as this variable is quantified and calibrated to reference standards, only the presence or absence of surface hydraulic connections can suggest the presence or absence of the variable.

Another time-saving approach is to use categorical estimates rather than continuous measures of indices. In the extreme case, the index would be present or absent, resulting in variables of 1.0 or 0.0, respectively. An alternative with somewhat better resolution, and that chosen herein for illustration

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page ix.

purposes, is to establish four discrete categories: 1.0, 0.5, 0.1, and 0.0. For a variable to have an index of 1.0, indicators must be judged to be "similar to the reference standard" (see definition of reference standards in Table 3). When quantified, this level may actually be in the range of 75 to 125 percent of the mean for the reference standard. Hence, it is important that variability in reference standard sites be reflected in the variables that are derived from them. For a variable to be in the 0.5 category, indicators are judged to be "less than reference conditions." This may fall in the range of 25 to 75 percent of the mean for the reference standard. Finally, a variable that falls in the range of 1 to 25 percent would receive an index of 0.1, while the lack of the variable (or indicators of it) would be assigned a zero.

Alternate approaches may be taken to encompass other conditions. For example, an index of 0.1 may be assigned for the variable if indicators are absent but the wetland has potential for recovery (that is, the impact may be reversible). An index of 0.1 may be chosen also to hedge judgment for indicators that are absent, but presence of the variable cannot be ruled out completely. The 0.1 index can be somewhat analogous to using "trace" as a measure of sparse plant cover. It is neither completely absent nor is it sufficiently important to warrant a higher index. Of course, an index of zero rules out the variable altogether. In some cases, alterations intentionally or inadvertently eliminate variables or perhaps functions completely from a wetland. For example, construction of artificial flood levees likely eliminates the "overbank flow" variable, V_{FREQ}.

Another approach having similar effects is the use of negative indicators. These may be based on some disturbance to the wetland which results in the partial or complete loss of a variable. For example, stream channelization usually eliminates overbank flow because channel capacity and conveyance have been increased with the intention of eliminating this variable. Consequently, functions that have frequency of overbank flow as a variable may be partially or totally lost.

When variables can be measured directly and quickly, or direct measures already exist for a site, there is no reason to use indicators. There are obvious advantages for having reference wetlands where indicators have been calibrated against quantitative data. In fact, the USGS has developed models for ungauged streams in many states to predict their hydrologic characteristics from gauged ones (e.g., Stamey and Hess 1993 for Georgia). For ungauged streams of riverine wetlands, such models could be applied to estimate frequency and duration of overbank flow.

Because riverine wetland assessments need to be tailored to specific regions of the country and their corresponding subclasses, there are no hard and fast rules on what qualifies as an indicator or how to use them. Indicators must be scaled to regional reference standards where the function is known to exist. This is especially true for habitat functions that deal with species of plants and animals that have limited biogeographic distribution. Indicators and variables should encompass conditions inherent to the reference domain.

In the HGM approach, levels of certainty (or uncertainty) are not determined for indicators, variables, or functions. The user is only responsible for applying the method to riverine wetlands insofar as the method is capable of detecting thresholds of functioning. The user does not have to ask the question "What is the certainty that the function exists?" This does not mean that the approach is free of uncertainty. Rather, there are degrees of uncertainty at every level in such assessments, and it would be extremely cumbersome to use and interpret results from a method that required both the assessment of function and the certainty that it exists. Certainty should be handled by the A-team in the regional refinement of the procedure. The A-team must decide whether enough information and evidence exists to use specific indicators and variables, and how variables should be combined for calculating functional indices. Certainty should become a property of the method rather than an additional factor to be assessed. Because this functional assessment procedure is completely open to review and examination, and the documentation explicit, anyone can judge certainty by applying the logic and becoming familiar with relevant literature. This has a twofold purpose: it allows the method to be scrutinized and improved by addition or change as new information becomes available on wetlands and their functions, and it allows details to be challenged or defended based on evidence and facts as they currently exist. There is no presumption that this assessment procedure is better or worse than any other approach just because it may have been adopted for use by a particular agency or firm. However, if parts of this method are regarded as unreliable, then the challenger must provide evidence to support such a conclusion. The intention of this approach is to improve consistency and predictability of decision making in wetland regulatory programs by applying the best science possible.

If an indicator or variable cannot be observed, yet there is no indication that the corresponding function is missing, one default option might be to assign scores of 1.0 to appropriate variables and functions. Other conventions could be developed as long as measures of certainty are not invoked to complicate the assessment and confound interpretation. If indicators or variables are not the kind that can be readily observed in a particular regional subclass, the A-team should explain why, and offer substitutes if appropriate.

The procedure should be field-tested by an A-team that develops regional reference standards. It would be prudent also to spend some time and money on quality control, including a comparison of the repeatability of the results among users and the reliability of the indicators, thresholds of indicators to verify a variable, and sensitivity of the equations to detect differences in functioning. Training should be an integral part of implementing functional assessments.

The scale between zero (no function) and 1.0 (reference standards) is probably adequate for most projects, especially those that completely displace vegetated wetlands with fill. Finer resolution may be needed where impacts are less acute, for example, where wetlands are subjected to slightly modified hydroperiods, accelerated nutrient loading, and increases in sediment deposition. Restoration projects that require measurements of changes over short periods of time may benefit from using expanded scales to detect significant but subtle changes toward specific project targets. In such cases, small annual changes that occur soon after the planting of wetlands may require that smaller differences be detected than is possible with a robust assessment scaled for major impacts. Indicators, equations, and models can be modified to accommodate specific needs not routinely encountered in regulatory programs. This does not require sacrificing an HGM approach, but rather refining and extending it to meet the needs of specific projects.

If the resolution for detecting changes is too coarse for routine assessments, and further attempts fail to improve indicators and variables, the A-team might consider developing finer subclasses. This may solve problems that originate from large amounts of variation in reference standards.

Scaling is done explicitly at the variable level so that absence of a variable receives a zero and its presence at the defined sustainable maximum (reference standards) is 1.0. Scaling is done implicitly at the function level, however, by combining indices of variables in equations in such a manner that wetlands representing the reference standard receive a score of 1.0. One of the most difficult concepts to understand is that indices of both variables and functions cannot exceed a level of 1.0. This is because **wetland ecosystems** are the unit of HGM assessments, not individual functions. Higher scores cannot be given to variables in the assessment area than are set for reference standards. Such an approach would violate the fundamental tenet that sustainable levels of ecosystem functioning cannot be maximized at the same time and on the same site. As a simple example, removal of trees from a wetland may slightly increase long-term surface water storage by providing more accessible space for water to be stored. This example illustrates two principles: such effects on single functions usually are not sustainable (that is, the forest will grow back on its own if not otherwise managed), and unsustainable increases in one function generally occur at the expense of other functions (that is, habitat conditions would be altered).

Any modifications to this method must be documented in order to maintain consistency among users. If this were not the case, there would be no reliable standards on what constitutes a function, how the function is determined, and what evidence is used for developing variables and indicators. The Documentation of Functions section is the core of the assessment method. As functions are updated and indicators are modified, both the documentation and forms used in fieldwork must be revised. The method will benefit from the experience of practitioners as they gain more insight into how functions relate to structure and the reference wetland database. Consequently, each version of the functions and field forms should carry the date on which they were approved and adopted so that previously conducted assessments can always be referenced to the version that was used at the time of assessment. Unless changes are substantial and require the measurement of additional indicators and application of additional variables, modified indices of functions should be easily reconstructed from previous versions and calibrated to those currently in existence. Modification of the "Documentation of Functions" for a regional subclass of wetlands should be controlled by an oversight committee that has regulatory responsibility, technical expertise, and familiarity with wetlands in the region of interest.

Documentation of functions

The portion of the guidebook on documentation (Chapter 2) is the core information for the 15 functions performed by most riverine wetlands (Table 4). Examples in the Riverine Guidebook are not specific for any physiographic region of the country, but rather are generic to provide a common point of departure for A-teams. First, these generic examples are adapted by A-teams for a particular physiographic region or subclasses of wetlands. Thereafter, procedures should be established for modifying the details by an experienced and knowledgeable group of practitioners according to some prescribed time schedule. This could be done by the A-team or others directed to update the procedure. Just as standards are developed and monitored by professionals in other disciplines, so should functional assessments be reviewed and updated by qualified experts. Summary tables of definitions of functions and variables are listed in Appendixes A and B.

Field form

The Documentation of Functions described above is the information that must be modified for the regional subclasses of riverine wetlands. That level of detail is inappropriate for use in the field while conducting assessments because of the large volume of material. Rather, a short form of the documentation, called the Field Form, is closer to what the practitioner might carry to the field. The Field Forms, in Appendix C, have two parts: (1) a synopsis of each function for reference in the field and (2) tally sheets for recording site identification and mode of assessment (i.e., project impact versus restoration), choosing indices of variables, and calculating the index for each function. The synopsis level of documentation is a suggested level of detail for fieldwork. Without it, there is a greater likelihood that the assessor will misinterpret the intent of the A-team in choosing certain indicators and variables. This is especially important when the assessor must predict functioning for restored wetland sites.

2 Documentation of Riverine Wetland Functions

Each riverine wetland function is described in the following order: definition, discussion of function and rationale, description of variables, index of function, and documentation.

Dynamic Surface Water Storage

Definition

The capacity of a wetland to detain moving water from overbank flow for a short duration when flow is out of the channel. This function is associated with moving water from overbank flow and/or upland surface water inputs by overland flow or tributaries.

Discussion of function and rationale

Detention of floodwaters is an important riverine wetland function. As overbank flow or upslope surface inputs are detained in the wetland, the timing of passage of the flood wave (wave celerity) is reduced. Alteration of the flood wave and detention of water may result in reduced downstream peak flows and delayed timing of the peak flows.

The movement of surface water through a wetland during an overbank flow event is controlled by width, slope, and roughness of the area inundated. The longer water is detained as it moves through the wetland, the greater the potential for the wetland to perform the function and to support other wetland functions.

Through the performance of this function, the wetland detains water long enough and reduces velocity sufficiently for particulate organic matter and sediments to settle out of the water column. Movement of water through a wetland redistributes organic and inorganic particulates and facilitates the import or export of plant propagules. Slow-moving water can also transport fine particulate organic matter away from the wetland to support food webs in connected aquatic environments. The spreading of water over the wetland and the settling of sediments and other particulates lead to an improvement of water quality. Infiltration of the flooded water into wetland soils can lead to support of other wetland functions, including nutrient cycling and removal of elements and compounds. The slower moving surface water in the wetland, in contrast to the higher velocity water in the stream channel, provides a refuge for aquatic organisms not well adapted to strong currents as well as a conduit for organisms to access the wetland for feeding and recruitment.

The frequency and duration of flooding from overbank flow are important dimensions of this function. If frequencies of overbank flow increase due to upstream modifications (e.g., urbanization), other functions may be modified even though the dynamic storage function is still occurring. If an increase in frequency and/or duration leads to increased sediment transport, the coating of plant leaves with silt may reduce photosynthesis, seedlings and seeds may become buried in sediment, and the site may become overloaded with nutrients. Consequently, the reference standard for this function must be selected carefully to recognize the principal physical attributes of the function, i.e., detention of surface water flowing through the wetland. The measurement of this function is critical because other attributes such as particulate retention and nutrient cycling are dependent on it.

The variables describing this function are related to the frequency and duration of overbank flow and wetland roughness features. Wetland slope may be a factor controlling the rate of surface water movement along the floodplain, particularly in low-order, steep-gradient systems. Major roughness features such as woody debris, macrotopography, and tree stems often dominate over slope. If major roughness features are not present in the reference standard sites, a slope variable may be added to compensate.

Description of variables

V_{FREQ}, ***Frequency of overbank flow***. The annual frequency at which a channel overtops its banks (when bank-full discharge is exceeded or water is delivered from upland sources) is important as a driving force for other wetland functions. Williams (1978) discusses methods for measuring bank-full discharge. Many studies have determined that bank-full discharge frequency for most streams is between 1.0 and 2.5 years, with 1.5 years being a reasonable average (Leopold 1994). Exceptions to this general conclusion are streams not in equilibrium due to strong down-cutting (degradation) of their channels into recent alluvial sediments, a result of past accelerated erosion and deposition. An example is the southeastern U.S. Piedmont where degrading channels may have a bank-full discharge frequency in excess of 10 to 25 years (Burke and Nutter, in press). Another example is oak flats in bottomland hardwoods where the recurrence intervals may be on the order of 2 to 5 years rather than 1.5 years.

Although the principal focus of this variable is overbank flow, it is recognized that some wetlands have substantial input from overland flow or tributaries (often ephemeral or intermittent streams) from adjacent uplands. A wetland may serve in these circumstances to provide the same moderation of the surface flow as occurs with overbank flow. A common situation in which these upland flows occur is from agricultural and urban runoff which may represent an altered condition. Comparison to the reference standard must be sensitive to the altered condition.

In the documentation section of this function, values given in parentheses indicate that other recurrence intervals could be used, depending on the reference domain. For example, recurrence intervals for oak flats would be approximately 2 to 5 years. With that as a reference standard, the 2- to 5-year recurrence would have an index of 1.0, with lower scores for altered conditions, e.g., <2 years or >5 years. The reference standard in this case must reflect the longer frequencies and, if annual flooding occurs in such circumstances, the index for the variable would be less than 1.0.

Contributions by overland flow and tributary input from the upland are also included in this variable. Although these flows are not technically overbank flow from a channel, the variable should account for them if they represent reference standards. If these sources are dominant in comparison to overbank flow, it should be noted whether they represent conditions of the reference standard or if they represent an alteration and should score below 1.0. The score for flooding at greater or less than recurrence intervals of the reference standard has an index of 0.5, e.g., a recurrence interval of greater or less than one-half year departure from the reference standard. Absence of flooding from overbank flow or from upland surface sources results in a score of zero.

V_{INUND}, ***Average depth of inundation***. Average depth of inundation should be determined for the overbank discharge event frequency used for V_{FREQ}. Of course, the surest method of determining the average depth is directly from nearby stage data extrapolated to the site in question. In the absence of stage data, regional relationships of peak flow discharge for different frequencies to basin area may be available from agencies such as the USGS. For an example of USGS state-specific studies for regional peak discharge relationships, see Stamey and Hess (1993) and for flood-depth frequency see Price (1977). An estimated peak discharge used in conjunction with calculation of channel and floodplain flow capacity by Manning's formula can be solved for flow depth at the time of peak discharge. Procedures for determining flow capacity by Manning's formula are given in many hydrology textbooks. The reader is directed to Chow, Maidment, and Mays (1988) and Dunne and Leopold (1978) for two levels of discussion on application of the Manning formula. Rosgen's (1994) methodology of stream classification is also a helpful tool for comparing channel systems and depth of inundation associated with their floodplain.

A wetland that has an average depth of inundation for the annual flood (or the recurrence interval indicated by the appropriate reference standard) equal to about 75 to 125 percent of the average reference standard scores 1.0. Lesser or greater inundation depths for the annual flood stage would have an index of 0.5 or 0.1, depending on degree of departure. The reasoning for assigning a lower index score to lesser or greater inundation depths is that the attainment of the function would be less under both conditions. For example, greater depths of inundation would likely not have as great an impact on timing of the flood wave, in comparison to the reference standard, than if the depth were within the 75- to 125-percent range. If the reference domain indicates otherwise, the variable can be appropriately scaled. If overbank flow or upland surface flow does not occur, depth of inundation is zero and the index score is zero.

***V_{MICRO}*, Microtopographic complexity**. Microtopography is a component of roughness that influences the tortuosity of flow pathways and reduces average velocity, and hence, detention time of surface water flowing through a wetland.

Deep flooding may cancel the effects of microtopographic complexity to the point that it does not have a significant effect on the function during major floods, especially in large, high-energy river systems. Microtopographic complexity should not be overlooked, however, because even minor relief may be important in detaining flood flow in low-energy systems. Further, microtopographic complexity is usually important for long-term surface water storage and vegetation and habitat functions.

As with depth of inundation, surface roughness between 75 and 125 percent of the reference standard scores 1.0. Departures from the reference standard are scored using the same approach as for depth of inundation. Microtopographic surveys are too costly for most applications. A suggested alternative is to make visual comparisons by recording the number of depressions or hummocks that fall within predetermined size (cross-section area and depth/height dimensions) classes per unit area (e.g., 10 by 10 m). For example, microdepression size classes might be 0.5, 1.0, and 1.5 m^2 and depths of 5, 10, and 15 cm.

Another empirical measure of roughness is Manning's roughness coefficient (n). This measure encompasses not only V_{MICRO}, but also roughness due to vegetation (e.g., V_{SHRUB}, V_{BTREE}, and V_{DTREE}) and coarse woody debris (V_{CWD}). A number of approaches can be used to estimate the coefficient; whichever method is used, it must account for floodplain roughness. The user is referred to Arcement and Schneider (1989) and Barnes (1967) for handbooks of photographs and measurements, and to local guides often available from the Natural Resources Conservation Service (NRCS) for suggested field methods to determine the roughness coefficient. Be sure to use an approach that allows determination of the floodplain roughness coefficient, since it is the floodplain wetland and not the stream channel that is performing the function. Floodplain values of n are given in Dingman (1994) and others.

Consultation with an experienced, local surface water hydrologist is another approach to selecting the appropriate coefficient. An assessment site with a Manning's n similar to the reference standard would score a 1.0. Sites with a somewhat significant positive or negative departure would score a 0.5, and significant departures would score a 0.1 or 0. If the Manning's n is difficult to determine, use the variables V_{MICRO}, V_{SHRUB}, V_{BTREE} or V_{DTREE}, and V_{CWD} without substitution.

Plant roughness variables. The density and size of woody stems (trees and shrubs) are major contributors to site roughness. These attributes create surface roughness that detain water. Stems also may trap organic debris ranging in size from leaves and twigs to logs. Trapped debris enhances the roughness and serves to further detain water by slowing water velocity.

In the discussion below, the woody vegetation roughness variable is separated into its components (trees and shrubs) and either an average or a weighted average is calculated to determine their scores. Energy Dissipation utilizes two vegetation roughness variables. In low-energy systems, it may be appropriate to consider cover or density of herbaceous plants in conjunction with woody vegetation roughness.

When assessing this variable with respect to the Dynamic Surface Water Storage function, keep in mind that the roughness contributed by stems and debris within the average depth of inundation (V_{INUND}) is represented by the roughness factors to be considered. It is for this reason that number of stems and concentration of woody debris on the ground are the metrics for direct or indirect measurement. The index of the variable is scored in the same manner as variable V_{MICRO}.

Direct measures of vegetation roughness are stem density (stems/acre) for trees and shrubs and basal area for trees. If a Manning's roughness coefficient is used, variables V_{MICRO}, V_{SHRUB}, V_{BTREE} or V_{DTREE}, and V_{CWD} may be combined, as explained in V_{MICRO}.

V_{SHRUB}, ***Shrub and sapling density, biomass, or cover***. Density, biomass, or cover of woody understory plants (shrubs and saplings). Shrubs and saplings contribute to the roughness mainly by clumps and/or number of stems. They tend to be more effective at higher densities because of their stature and resistance.

V_{DTREE}, ***Tree density***. Density of large-diameter canopy trees (V_{BTREE} may be used instead). Tree density, although low relative to shrubs and herbaceous plants, creates roughness that is especially effective at high flows and in deep water. Secondary effects are the entrapment of coarse woody debris, which can further increase site roughness.

V_{BTREE}, ***Tree basal area***. Basal area or biomass of trees (V_{DTREE} may be used instead). Basal area is easy to measure and is somewhat proportional to the surface area of stems in contact with flowing water, thus contributing to site roughness.

V_{CWD}, ***Coarse woody debris***. Coarse woody debris (CWD) on floodplains contributes to roughness, hence, slowing the movement of water and ameliorating flooding downstream. CWD includes dead and downed trees and limbs larger in diameter than some predetermined size (usually greater than 10 cm in diameter and longer than 1 meter) appropriate to the reference standard of the regional geomorphic class being assessed. The ecological significance of CWD is described in more detail in the section Maintain Characteristic Detrital Biomass. For example, a much higher biomass for CWD would be expected for high-energy floodplains of old-growth forests in the Pacific Northwest than for an equivalent geomorphic riverine class in the eastern United States or in urban areas.

Several methods have been developed for measuring CWD (Harmon et al. 1986), but almost all express the variable in volume per unit area. Average diameters and lengths of stems could be measured or their density estimated in plots for comparison with reference standards. Overall roughness can be calculated using Manning's roughness coefficient to replace variables V_{MICRO}, V_{SHRUB}, V_{BTREE} or V_{DTREE}, and V_{CWD}.

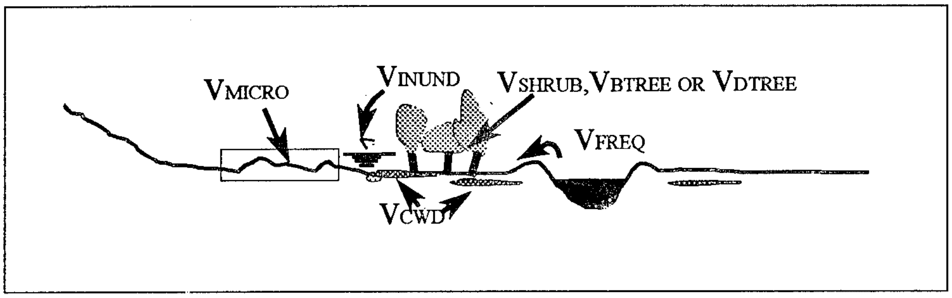
Index of function

For Dynamic Surface Water Storage, the variables are frequency of overbank flow (V_{FREQ}), average depth of inundation (V_{INUND}), microtopographic complexity (V_{MICRO}), woody vegetation roughness (V_{SHRUB}, V_{BTREE}, or V_{DTREE}), and coarse woody debris roughness (V_{CWD}). Overbank flow or upland surface flow is an absolute requirement for this function; if it does not occur, the index score is zero as depicted in the equation. If depth and roughness variables are all absent, the index score is also zero. It is assumed that both factors are equally important in the reference standard. A slope variable may be appropriate to add for low-order, steep-gradient systems.

$$\mathit{Index\ of\ Function} = [V_{FREQ} \times (V_{INUND} + V_{MICRO} + V_{SHRUB} + V_{BTREE}\ \mathit{or}\ V_{DTREE} + V_{CWD})/5]^{1/2}$$

If the Manning's roughness coefficient is used to aggregate variables V_{MICRO}, V_{SHRUB}, V_{BTREE}, V_{DTREE}, and V_{CWD}, the equation becomes

$$\mathit{Index\ of\ Function} = [V_{FREQ} \times (V_{INUND} + V_{MICRO,\ SHRUB,\ BTREE\ or\ DTREE,\ and\ CWD})/2]^{1/2}$$



Documentation

DYNAMIC SURFACE WATER STORAGE

Definition: Capacity of a wetland to detain moving water from overbank flow for a short duration when flow is out of the channel; associated with moving water from overbank flow and/or upland surface water inputs by overland flow or tributaries.

Effects Onsite: Replenishes soil moisture; import/export of materials (i.e., sediments, nutrients, contaminants); import/export of plant propagules; provides conduit for aquatic organisms to access wetland for feeding, recruitment, etc.

Effects Offsite: Reduces downstream peak discharge; delays downstream delivery of peak discharges; improves water quality.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{FREQ}: Frequency of overbank flow	Gauge data (1.5) yr return interval similar to reference standard. (Interval in parentheses must be adjusted to the reference standard.)	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0
	Gauge data (>2 or <1) yr return interval.	As above, but somewhat greater or less than reference standard.	0.5
	Gauge data show extreme departure from reference standard.	Above indicators absent but related indicators suggest overbank flow may occur.	0.1
	Gauge data indicate no flooding from overbank flow.	Indicators absent and/or there is evidence of alteration affecting variable.	0.0
V_{INUND}: Average depth of inundation	Gauge data indicate that depth is between 75% and 125% that of reference standard.	Height of water stains and other indicators of water depth (ice scars, bryophyte lines, drift and/or wrack lines, etc.) between 75% and 125% of reference standard.	1.0

V_{INUND}: (Concluded)	Gauge data indicate depth is <75% or >125% of reference standard.	Height of water stains and other indicators of water depth (ice scars, bryophyte lines, drift and/or wrack lines, etc.) <75% of reference standard.	0.5
	Gauge data indicate infrequent or minor overbank flooding relative to reference standard.	Above indicators absent but related indicators suggest variable may be present.	0.1
	Gauge data indicate flooding does not occur.	Indicators absent and/or evidence of alteration affecting the variable.	0.0
V_{MICRO}: Microtopographic complexity	Microtopographic complexity (MC) measured (surveyed) shows MC >75% to <125% of reference standard.	Visual estimate indicates that microtopographic complexity (MC) is >75% and <125% of reference standard.	1.0
	Measured MC is between 25% and 75% that of reference standard.	Visual assessment confirms MC is present, but somewhat less than reference standard.	0.5
	Measured MC between 0% and 25% that of reference standard; restoration possible.	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1
	No MC at assessed site or natural substrate replaced by artificial surface.	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0
V_{SHRUB}: Shrub and sapling density, biomass, or cover	Shrub abundance >75% that of reference standard.	Visual estimate of shrubs and saplings indicates site is similar (>75%) to reference standard.	1.0
	Shrub abundance between 25% and 75% that of reference standard.	Visual estimate of shrubs and saplings indicates site is between 25% and 75% that of reference standard.	0.5
	Shrub abundance between 0% and 25% that of reference standard.	Shrubs and saplings are sparse or absent relative to reference standard; restoration possible.	0.1
	Shrubs absent; restoration not possible.	Shrubs absent; restoration not possible.	0
V_{BTREE}: Tree basal area (V_{DTREE} may be used instead)	Basal area or biomass is greater than 75% of reference standard.	Stage of succession similar to reference standard.	1.0
	Basal area or biomass between 25% and 75% of reference standard.	Stage of succession departs significantly from reference standard.	0.5
	Basal area or biomass between 0% and 25% of reference standard; restoration possible.	Stage of succession at extreme departure from reference standard.	0.1
	No trees present; restoration not possible.	Stand cleared without potential for recovery.	0.0

V_{DTREE}: Tree density (V_{BTREE} may be used instead)	Measured or estimated tree density between 75% and 125% of reference standard.	Stage of succession similar to reference standard.	1.0
	Tree density between 25% and 75%, or between 125% and 200% of reference standard.	Stage of succession departs significantly from reference standard.	0.5
	Tree density between 0% and 25% or greater than 200% of reference standard; restoration possible.	Stage of succession at extreme departure from references standard; restoration possible.	0.1
	No trees are present; restoration not possible.	Stand cleared; no restoration possible.	0.0
V_{CWD}: Coarse woody debris	Biomass of CWD is >75% and <125% of reference standard.	Average diameters and lengths of CWD is >75% and <125% of reference standard.	1.0
	Biomass of CWD is between 25% and 75% that of reference standard.	Average diameters and lengths of CWD is between 25% and 75% that of reference standard.	0.5
	Biomass of CWD is between 0% and 25% that of reference standard; restoration possible.	Average diameters and lengths of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1
	No CWD present; restoration not possible.	No CWD present; restoration not possible.	0.0

Option 1:

$$\textit{Index of Function} = [V_{FREQ} \times (V_{INUND} + V_{MICRO} + V_{SHRUB} + V_{BTREE} \textit{ or } V_{DTREE} + V_{CWD})/5]^{1/2}$$

If the Manning's roughness coefficient is used to aggregate variables V_{MICRO}, V_{SHRUB}, V_{BTREE} or V_{DTREE}, and V_{CWD}, the equation becomes

Option 2:

$$\textit{Index of Function} = [V_{FREQ} \times (V_{INUND} + V_{MICRO,\ SHRUB,\ BTREE\ or\ DTREE\ and\ CWD})/2]^{1/2}$$

Long-Term Surface Water Storage

Definition

Long-term surface water storage is the capacity of a wetland to store (retain) surface water for long durations. The source of water may be overbank flow, overland flow, tributary flow, subsurface flow from uplands, or direct precipitation. Long-term surface water storage is associated with standing water in the wetland that is not moving over the surface. Durations vary with region, but long-term storage may be considered to begin when overbank flow retreats into the channel and is present in the wetland for more than 7 days. When the source of water is direct precipitation or from upland sources, long-term storage is water ponded until lost by evapotranspiration and drainage.

Discussion of function and rationale

As with the dynamic surface water storage function, long-term surface water storage has both hydrologic and ecological importance (Gosselink and Turner 1978). Many river systems possess wetlands that cover broad, flat floodplains. Therefore, water may pond over the surface of these wetlands for long periods of time in backswamp areas, behind natural levels, in old meander scars, in depressions and pits, etc. Ponding is considered long term if it lasts for a week or longer, because shorter durations in most cases are not long enough to be critical to other variables associated with soil anaerobiosis, biogeochemical processes, and invertebrate habitat. An increase in duration of long-term storage, such as occurs from backwater (channel restrictions) and impoundments, can have an adverse impact on hydrologic and ecologic functions (Conner and Day 1989).

If the source of water is overbank flow, retention of floodwater in the wetland will decrease the volume of floodwater transported downstream. The portion of the retained water that infiltrates and recharges surficial groundwater may become base flow at a later time, thus contributing to higher base flows and moderated distribution of seasonal flows. Ponding may also diminish gaseous exchange between the atmosphere and soil, prohibit the germination of seeds, lead to prolonged soil saturation (quite often longer than the period of ponding), provide support for aquatic vertebrates and invertebrates, and contribute to other ecological processes. Colloidal inorganic and organic sediments with sorbed nutrients and contaminants will settle during the prolonged ponding and contribute to other functions.

If the principal source of water is other than overbank flow, this function is still important to the overall functioning of a wetland. The same onsite effects are likely to occur when other sources dominate, except there will be no moderation of a flood hydrograph because water did not enter the wetland by overbank flow.

Description of variables

V_{SURWAT}, ***Indications of surface water presence***. For the Long-Term Surface Water Storage function to occur, a wetland must be inundated by ponded or retained water for a continuous period of not less than 1 week. Site assessments are not always possible when there is the presence of surface water for the requisite continuous duration. Use of this variable assumes that if surface water is present, it is present for the required duration. Therefore, local indicators must usually be developed as indirect measures of presence and duration. It is suggested that a hierarchy of decision points be used to determine if ponded water has or is expected to occur; if the ponding is continuous; and if continuous, the duration of ponding.

Indicators of presence of ponding (such as drift lines) may not indicate much about continuity and duration. Other indicators such as the absence of regeneration of annual plants or water-stained leaves may imply continuity and duration of ponded water. It is recommended that, during the establishment of the reference standard for this variable, observation of local indicators as tied to direct measures be noted to aid in the interpretation of assessment sites.

Other indicators of ponded water include direct observation, appearance on aerial photographs, inference from NRCS soil series descriptions, water balance calculations using local rainfall and evapotranspiration data, or calculations of streamflow or staff gauge data indicating the occurrence of overbank flow that would fill depressions, backswamps, or trap water behind natural levees.

Indirect indicators of the presence of water ponded over the long term are the absence of herbaceous vegetation (indicating that soil surfaces are not exposed during normal germination and emergence periods), organic matter accumulation in the soil, and low permeability or infiltration rates of the soil.

Low infiltration capacity can be inferred from NRCS hydrologic soil groups C or D (if soil series is known). The NRCS hydrologic soil groups are used in the runoff curve number approach to predict stormflow volumes. The hydrologic soil group for all soil series are published in modern Soil Surveys and in soil series interpretations. Groups C and D have the lowest infiltration capacity and therefore the highest stormflow production potential. Because of soil variability, particularly in alluvial riverine settings, the published hydrologic soil group may not be the best indicator of infiltration capacity and ponding ability. If used as an indicator, the soil groups should be verified in the field and used in conjunction with other indicators. However, if soils with low infiltration are not part of reference standards, other indicators should be used for this variable.

If surface water is present more often than not, and the principal water source for maintenance of ponding condition is other than overbank flow, it may be advisable to place the wetland in a depressional class. Slow losses of ponded water through a constricted outlet (e.g., oxbow depression) would indicate its connection with a riverine system.

Sites equivalent to the reference standard based on the presence of either direct or indirect indicators score 1.0. Less strong indications of long-term storage in comparison with the reference standard are scored lower. The highest score of 1.0 is generally associated with strong indications that water is ponded for long periods of time at least once each year during the growing season. Lack of conditions to pond water or presence of an altered condition scores zero.

V_{MACRO}, ***Macrotopographic relief***. For long-term storage to occur, particularly when a stream has retreated to within its banks, there must be topographic relief on the floodplain that consists of restricted outlets thus allowing surface water to be trapped for the requisite duration. Relief features on a sloping landscape that will not serve to trap water for long periods do not contribute to the expression of this variable.

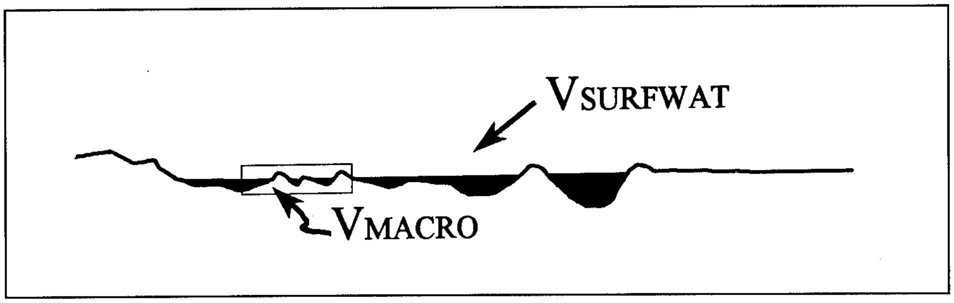
Macrotopographic relief features include oxbows, meander scrolls, abandoned channels, and backswamps. Each of these features in a riverine setting is often associated with a particular landform or landscape setting and stream order. Such macrotopographic features are usually found in higher order streams or streams with steep gradients. Low-energy systems and small stream floodplains with low gradients usually lack such distinctive macrotopographic features. Therefore, this variable should not be used in modeling the Long-Term Surface Water Storage function if it is not present in reference standard sites.

When the macrotopographic relief features are similar to reference standards, such as being well formed on a wetland with little or no surface gradient, the variable index is 1.0. Where relief features have been altered so that they do not serve to trap water for long periods, the site should be scored lower (0.5 or 0.1), depending on the rate at which surface drainage might occur relative to the reference standard. If macrotopographic relief is not significant and the surface gradient is moderate to steep, indicating a rapid loss of water or that no ponding occurs relative to reference standards, the variable index is zero. Altered wetlands may have their macrotopographic features reduced or made ineffective through filling, leveling, and drainage.

Index of function

Presence of water (V_{SURWAT}) and macrotopographic relief (V_{MACRO}) are variables associated with the Long-Term Surface Water Storage function. There is no variable directly related to the actual length of time that water is present on the surface; rather, time of ponding (inferred by vegetation and soil indicators of processes) is compared with the reference standard. Longer times of ponding are not critically important to offsite effects of this function since the main effect is the reduction of flow peaks. In some wetland ecosystems, the length of time may be critical to some onsite ecological processes and wetland functions. When this is the case, a time of ponding variable should be added to the model (consider using V_{DURAT}). The same index must be used for the assessed wetland as for reference standard sites.

$$Index\ of\ Function = (V_{SURWAT} + V_{MACRO})/2$$



Documentation

LONG-TERM SURFACE WATER STORAGE

Definition: Capacity of a wetland to temporarily store (detain) surface water for long durations; associated with standing water not moving over the surface. Sources of water may be overbank flow, direct precipitation, or upland sources such as overland flow, channel flow, and subsurface flow.

Effects Onsite: Replenishes soil moisture; removes sediments, nutrients, and contaminants; detains water for chemical transformations; maintains vegetative composition; maintains habitat for feeding, spawning, recruitment, etc., for pool species; influences soil characteristics.

Effects Offsite: Improves water quality; maintains base flow; maintains seasonal flow distribution; lowers the annual water yield; recharges surficial groundwater.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{SURWAT}: Indicators of surface water presence	1. Gauge data indicate overbank flow sufficient to pond water or 2. Direct observation of ponded water or 3. Aerial photo evidence confirms flooding similar to reference standard.	Compared to regional reference standard: 1. Annual understory (grass and woody reproduction, etc., absent) or 2. High organic matter accumulation at soil surface or 3. Massive soil structure with low permeability and general lack of small roots in the surface soil horizon or 4. NRCS Hydrologic Soil Group C or D when soil series known.	1.0

V_{SURWAT}: (Concluded)		As above, but below reference standard.	0.5
		Above indicators absent but related indicators suggest variable may be present.	0.1
	Gauge data indicate no overbank flow; ponding minor or not evident; no evidence of flooding on aerial photos.	Indicators absent and/or there is evidence of alteration affecting variable.	0.0
V_{MACRO}: Macrotopographic relief	1. Contour maps indicate gross relief and/or closed contours similar to reference standard or 2. Topographic survey shows relief similar to reference standard.	Oxbows, meander scrolls, abandoned channels, backswamps, etc., similar in magnitude to reference standard.	1.0
		Indicators above much less developed than reference standard and area has a low surface gradient.	0.5
	Maps and/or topographic survey indicate relief very dissimilar to reference standard.	All above indicators absent and area has a moderate to steep gradient.	0.0

$$Index\ of\ Function = (V_{SURWAT} + V_{MACRO})/2$$

Energy Dissipation

Definition

Allocation of the energy of water to other forms as it moves through, into, or out of the wetland as a result of roughness associated with large woody debris, vegetation structure, micro- and macrotopography, and other obstructions.

Discussion of function and rationale

This function not only pertains to rate of flow through the wetland, partially accounted for by Dynamic Surface Water Storage, but is related more to how energy is expressed in the water flowing into, through, and out of a wetland. In high-energy streams, common in the Pacific Northwest and other mountainous regions, large woody debris and boulders are moved in the channel and onto wetlands. As a result of energy dissipation within wetlands, pressure on channel beds and banks is lower so the system is more stable.

For example, a recently clear-cut forested riparian area will have few trees in place for large woody debris to lodge against. Energy that would otherwise be dissipated in the floodplain will be transferred to channel scour, channel clogging by debris, and movement/ deposition of sediment. Similar hydrologic processes occur in lower energy systems with less obvious expressions, but no less important to the functioning of wetlands.

Energy dissipation has secondary effects as well. Deposition of large woody debris within a wetland not only enhances the function but also is important to biogeochemical functions (Lisle 1995). Dissipated energy expressed as scour holes and sediment deposition may also enhance dynamic and long-term surface water storage by creating more topographic relief and surface roughness. An offsite hydrologic expression of the energy dissipation function is the reduction in flood peak, flood wave celerity, and improved water quality (i.e., less sediment). Channelized streams are designed to increase channel velocity and minimize overbank flow. The resultant channel flow (unless artificially stabilized) will undercut banks, and the channel will begin a meandering process to dissipate the energy.

Description of variables

V_{REDVEL}, ***Reduction in flow velocity.*** Critical to dissipation of energy is reduction in water velocity as it passes through the wetland. Velocity is reduced by surface roughness and obstructions, and by spreading of water over a larger area (the wetland). In using the general relationship of discharge (Q) equals mean velocity (V) times cross section of flow area (A), an increase of A results in a proportional reduction in V.

Direct measures of velocity reduction are difficult; rarely is one at the site at the time of a flood event. Velocity of flow within the wetland may be estimated by use of Manning's formula, but careful selection of the roughness coefficient for the floodplain must be made. (See discussion for the Dynamic Surface Water Storage function, V_{INUND}, for a discussion of the roughness coefficient.) A local table of roughness coefficients could be developed to estimate relative differences between wetland conditions that could be related to expected velocity reductions.

The stronger the expression of velocity reduction in a wetland, the greater its index score relative to the reference standard. Sediment deposits, scour, buried root collars, and large woody debris deposited or moved about indicate a wetland's capacity to reduce velocity. When velocity reduction is not clearly evident at the reference wetland sites by the above indicators, the site roughness variables identified below should be used instead. The rationale is that velocities are not great or site roughness has contributed to a marked reduction in velocity as overbank flow occurs. The observer must make the distinction based on local knowledge and best professional judgment.

In systems where gradient (none to steep) is a dominant factor in reducing velocity and is exhibited by the indicators, a slope variable may be added to the regional model. Slope combined with the roughness and overbank flow variables may be an appropriate model in low-order, steep-gradient riverine systems.

An alternative to direct measures of velocity are estimates, perhaps by Manning's equation, of the ratio of expected velocities in the channel at bank-full stage and expected velocity at V_{INUND}. A velocity reduction ratio within 75 percent of the reference standard would score 1.0, and lesser reductions would score 0.5 or 0.1. No reduction would score a zero.

V_{FREQ}, ***Frequency of overbank flow.*** For flow energy to be dissipated, water must enter a wetland. Therefore, the frequency and occurrence of overbank flow to a riverine wetland is critical to this function. Flooding recurrence intervals used for assessment of this function must be tied to the reference standard. Absence of overbank flow negates the function for the frequent events and the variable scores zero. Riverine wetlands that do not experience frequent (annual) overbank flows are usually not high-energy systems, and so energy dissipation on short recurrence intervals by such wetlands may not be critical. Rather, it may be during long recurrence-interval events (e.g., 50- and 100-year events) that incised wetlands may play a critical role in dissipation of these high-energy overbank flows. Such high-energy, infrequent flows often reset riverine wetlands by creating scour holes, depositing sandbars, and importing or moving about large woody debris and other similar features.

The use of parentheses in the documentation of this variable indicates that other recurrence intervals could be used relative to the reference domain. For example, recurrence interval for oak flats would be approximately 2 to 5 years. In this case, a 2- to 5-year recurrence would have an index of 1.0, with lower scores for altered conditions, e.g., less than 2 years or greater than 5 years.

Overbank flow is best quantified by hydrographic data that can be used as a direct measure of this variable. Such data may be obtained from either federal or state agencies that maintain hydrogeographic databases. The reference standard is the frequency of overbank flow found in reference standard sites. If the frequency of overbank flow of the assessment site has a frequency of 75 to 125 percent, a score of 1.0 is given. If the frequency is 25 to 75 percent or >125 percent, compared to reference standards, an index score of 0.5 is given. If the assessment area rarely floods (>0 to <25 percent), 0.1 is recorded. If there is no flooding of the wetland by overland flow, the variable receives a zero.

V_{MACRO}, V_{MICRO}, V_{DTREE}, V_{CWD}, ***Site roughness.*** If indicators of velocity reduction are not readily interpreted, a site roughness complex variable may be used instead. As size and number of obstacles to surface flow increase, the potential for energy dissipation increases. As water flows over surfaces, friction and shear forces create turbulent flow and reduce velocities. These critical gross features of site roughness are characterized by macrotopographic relief (V_{MACRO}), microtopographic complexity (V_{MICRO}), numbers of trees (V_{DTREE}), and the size, distribution, or volume of coarse woody debris (V_{CWD}).

The more complex the roughness and the more stable its structure (large-diameter stems, large woody debris lodged against tree stems), the greater the potential for energy dissipation. As with the Long-Term Surface Water Storage function, the microtopographic complexity variable (V_{MICRO}) may not be appropriate for high-energy riverine systems. The four variables are scaled independently. However, Manning's coefficients have been developed for site-specific data to attempt to provide quantitative relationships between roughness and wetland structure (Arcement and Schneider 1989). This coefficient integrates all variables of roughness which, if information were available, would allow the collapsing of V_{MACRO} through V_{CWD} into one variable (see Dynamic Surface Water Storage function as an example). However, care must be exercised if Manning's roughness coefficient is used for making field comparisons, because many tables of values do not include large features that may occur in some wetlands, particularly large woody debris found in the Pacific Northwest.

Each of the roughness components should be evaluated separately unless there are available guidelines for Manning's n. A complex and stable roughness system comparable to the reference standard scores a 1.0, and as complexity decreases, the score decreases to 0.1. Estimates below reference standard score 0.5 unless roughness is virtually absent. Smoothed, graded surfaces receive 0.1 or zero depending on the potential for recovery.

Index of function

Reduction in flow velocity (V_{REDVEL}), frequency of overbank flow (V_{FREQ}), and site roughness (V_{MACRO}, V_{MICRO}, V_{DTREE}, V_{CWD}) are the variables describing the function. These variables must be scaled to reference standards appropriate to the hydrologic regime. The variables are combined to express the function index as follows:

$$\textit{Index of Function} = (V_{FREQ} \times V_{REDVEL})^{1/2}$$

or

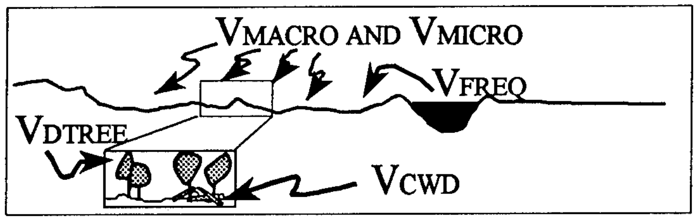
$$\textit{Index of Function} = \{V_{FREQ} \times [(V_{MACRO} + V_{MICRO} + V_{DTREE} + V_{CWD})/4]\}^{1/2}$$

or

if Manning's n is used as a surrogate for the site roughness factors,

$$Index\ of\ Function = [V_{FREQ} \times (V_{MACRO,\ MICRO,\ DTREE,\ CWD})]^{1/2}$$

It is assumed that each of the combined roughness variables, frequency of overbank flow, and reduction of flow velocity are equally important in maintaining the function in reference standards.



Documentation

ENERGY DISSIPATION

Definition: Allocation of the energy of water to other forms as it moves through, into, or out of the wetland as a result of roughness associated with large woody debris, vegetation structure, micro- and macrotopography, and other obstructions.

Effects Onsite: Increases deposition of suspended material; increases chemical transformations and processing due to longer residence time.

Effects Offsite: Reduces downstream peak discharge; delays delivery of peak discharges; improves water quality; reduces erosion of shorelines and floodplains.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{REDVEL}: Reduction in flow velocity	Velocity in wetland >75% of that expected in reference standard sites.	Sediment deposits, silt deposits on vegetation, buried root collars, stacked wracks of debris, etc., similar to reference standard.	1.0
	Less than 75% reduction in velocity relative to standard.	Sediment scour, scoured root collars, large woody debris moved about; erosion of soil surface, etc., indicating less than reference standard.	0.5
		Directionally bent vegetation, bare soil exposed (not sediment deposits), strongly departing from reference standard.	0.1

V_{REDVEL}: (Concluded)	No reduction in velocity by direct measurement.	Strong evidence of severe site degradation by channel scour, exposed root masses, suggesting variable is absent.	0.0
V_{FREQ}: Frequency of overbank flow	Gauge data (1.5) yr return interval; within 75% and 125% of reference standard. (Intervals in parentheses must be adjusted to the reference standard.)	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0
	Gauge data (>2 or <1) yr return interval; 25% to 75% or >125% of reference standard.	As above, but somewhat greater or less than reference standard.	0.5
	Gauge data show extreme departure from reference standard, e.g., 0% to 25%.	Above indicators absent, but related indicators suggest overbank flow may occur.	0.1
	Gauge data indicate no flooding from overbank flow.	Indicators absent and/or there is evidence of alteration affecting variable; restoration not possible.	0.0
V_{MACRO}: Macrotopographic relief	1. Contour maps indicate gross relief and/or closed contours similar to reference standard or 2. Topographic survey shows relief similar to reference standard.	Oxbows, meander scrolls, abandoned channels, backswamps, etc., similar in magnitude to reference standard.	1.0
		Indicators above much less developed than reference standard, and area has a low surface gradient.	0.5
	Maps and/or topographic survey indicates relief very dissimilar to reference standard.	All above indicators absent and area has a moderate to steep gradient.	0.0
V_{MICRO}: Microtopographic complexity	Microtopographic complexity (MC) measured (surveyed) shows MC > 75% to < 125% of reference standard.	Visual estimate indicates that microtopographic complexity (MC) is >75% and <125% of reference standard.	1.0
	Measured MC is between 25% and 75% that of reference standard.	Visual assessment confirms MC is present, but somewhat less than reference standard.	0.5
	Measured MC between 0% and 25% that of reference standard; restoration possible.	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1
	No MC at assessed site of natural substrate replaced by artificial surface.	Visual assessemnt indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0

V_{DTREE}: Tree density	Measured or estimated tree density between 75% and 125% of reference standard.	Stage of succession similar to reference standards.	1.0
	Tree density between 25% and 75%, or between 125% and 200% of reference standard.	Stage of succession departs significantly from reference standards.	0.5
	Tree density between 0% and 25%, or greater than 200%, of reference standard; restoration possible.	Stage of succession at extreme departure from reference standards; restoration possible.	0.1
	No trees are present; restoration not possible.	Stand cleared; no restoration possible.	0.0
V_{CWD}: Coarse woody debris	Biomass of CWD >75% and <125% that of reference standard.	Average diameters and lengths of CWD is >75% and <125% that of reference standard.	1.0
	Biomass of CWD between 25% and 75% that of reference standard.	Average diameters and lengths of CWD is between 25% and 75% that of reference standard.	0.5
	Biomass of CWD is between 0% and 25% that of reference standard; restoration possible.	Average diameters and lengths of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1
	No CWD present; restoration not possible.	No CWD present; restoration not possible.	0.0

$$Index\ of\ Function = (V_{FREQ} \times V_{REDVEL})^{1/2}$$

or

$$Index\ of\ Function = \{V_{FREQ} \times [(V_{MACRO} + V_{MICRO} + V_{DTREE} + V_{CWD})/4]\}^{1/2}$$

or

If Manning's n is used as a surrogate for the site roughness factors,

$$Index\ of\ Function = [V_{FREQ} \times (V_{MACRO,\ MICRO,\ DTREE,\ CWD})]^{1/2}$$

It is assumed that each of the combined roughness variables, frequency of overbank flow, and reduction of flow velocity are equally important in maintaining the function in reference standards.

Subsurface Storage of Water

Definition

Availability of storage for water beneath the wetland surface. Storage capacity becomes available as periodic drawdown of the water table or reduction in soil saturation occurs, making drained pores available for storage of water. Drawdown may be the result of vertical and lateral drainage and/or evapotranspiration.

Discussion of function and rationale

Evacuated pores provide available volume for storing water entering a wetland. The absorption and storage of water below-ground can reduce the depth of wetland inundation and slow the release of water to the stream (in contrast to surface flow directly to the channel). Below-ground storage also helps to maintain base flows. The ability of soils with small pores to absorb and hold water for long periods favors the survival of plant species that can most tolerate long periods of saturation (obligate and facultative wet hydrophytes).

A soil's potential for subsurface storage is a function of the size and abundance of the soil pore spaces and antecedent degree of saturation. Although clay soils possess more pore space than sandy soils, the smaller size of pores in clay retards the rate of both absorption and release of water. For this reason, clay soils usually possess a lower capacity to store water than sandy soils.

The degree of saturation of a soil is affected by prior flooding events, precipitation and other inputs, and rate and extent of water table drawdown. This determines actual storage capacity at a particular point in time. Frequent floods (a seasonal phenomenon in some areas) or a constant input of water (either ground or surface water) may render a wetland soil incapable of additional storage of water. Alterations of hydrology that create inundation (e.g., beaver activity) or saturation to the surface also alter this function.

Storage of water beneath the wetland surface supports ecological processes and maintains hydrologic processes. As water is evacuated from porous media (mineral or organic soils) as a result of drainage or evapotranspiration, gaseous exchange readily occurs and empty pores are filled with air. This fluctuation between aerobic and anaerobic conditions benefits the recruitment, survival, and competitiveness of wetland plant species and sustains environmental conditions necessary for microbially mediated biogeochemical cycling.

Description of variables

V_{PORE}, ***Soil pore space available for storage.*** Soil texture and drawdown of the water table or reduction in soil saturation (creating air-filled pores) are factors that must be considered in scaling this variable. Coarse soil textures (sandy loams and coarser) and water tables that fluctuate within 15 to 30 cm of the surface, yet maintain wetland soil wetness conditions, would have a high potential for providing volume of empty pore space for subsurface water storage. Finer texture soils that have a capillary fringe extending to near the surface would have a low potential for subsurface storage. Sites saturated to the surface or ponded for long periods of time have little or no potential for subsurface storage.

Caution must be exercised in specifying a reference standard for this function's variables because the "wetter" a wetland is, the lower its index score. So it is important that the reference standard be correctly identified both in terms of degree of soil wetness, rate of drainage or water table drawdown, and soil texture. The time of year that this function should be defined is when the riverine wetland is subject to the most frequent flooding (i.e., the annual flood). It is during this period of time that the variables are most critical to the function. The variables are less important for less frequent floods that are preceded by high rainfall, thereby saturating the soil and reducing the potential for subsurface storage. Frequent flooding that leads to long-term soil saturation or inundation also reduces the capacity for subsurface storage.

For comparative purposes the available water storage capacity for soil series horizons (NRCS Soil Surveys) can be used to determine the potential pore space available for storage if the soil were drained. The degree of saturation and position of the water table must then be considered to determine how much of the pore space will be available for subsurface storage.

Comparisons must be made to similar conditions defined by the reference standard. Sites similar to the reference standard for soil textures and fluctuating water table or degree of soil saturation score an index of 1.0. Sites that do not meet the reference standard score zero when no subsurface storage is available.

V_{WTF}, ***Fluctuation of water table.*** The water tables of most riverine wetlands undergo drawdowns due to evapotranspiration and drainage, and rises due to precipitation and flood events. Drawdowns combine with pore space to provide potential volume for storage of water below the wetland surface.

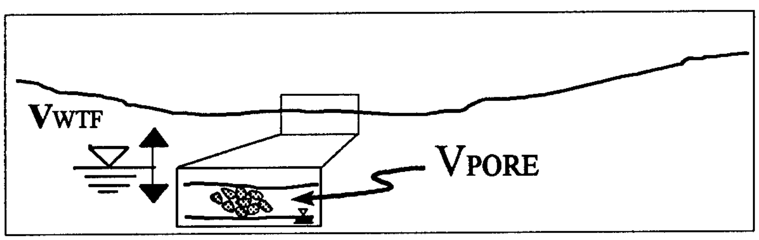
Fluctuations in the water table can be directly measured as depth to water table from the surface in wells screened throughout the depth interval of fluctuation. High frequency measurements (> 1/day) can be made in association with data loggers; alternatively, less frequent measurements would approximate the range in fluctuations on a seasonal basis. During a period of high evapotranspiration rates, water tables may fluctuate several inches per day. Thus, frequent measurements are sometimes needed during the growing season. Redoximorphic features such as mottling and formation of concretions may also serve as an indicator for water table fluctuation. However, such indirect measures need to be calibrated with seasonal water table dynamics over more than one growing season. Water balance models may also be applied to estimate water table drawdown under prevailing climatic conditions.

If water tables fluctuate between 75 and 125 percent of the reference standard, the variable should receive a score of 1.0. For fluctuations between 25 and 75 percent or greater than 125 percent, a variable score of 0.5 should be assigned. Fluctuations between zero and 25 percent should receive a score of 0.1. Static water tables and water tables that remain much too deep for comparison with reference standards are scored zero.

Index of function

The subsurface storage model is simply the variable soil pore space available for storage. The index is

$$Index\ of\ Function = (V_{PORE} + V_{WTF})/2$$



Documentation

SUBSURFACE WATER STORAGE

Definition: Availability of water storage beneath the wetland surface. Storage capacity becomes available as periodic drawdown of water table or reduction in soil saturation occurs.

Effects Onsite: Short- and long-term water storage; influences biogeochemical processes in the soil; retains water for establishment and maintenance of biotic communities.

Effects Offsite: Surficial groundwater recharge; maintains base flow; maintains seasonal flow distribution.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{PORE}: Soil pore space available for storage	Example: The reference standard is sandy loam to coarser texture soil with good structure (abundant macropores).	Use direct measure.	1.0
	Soil textures finer than sandy loam.	Use direct measure.	0.5
	Soil saturated to surface or ponded for long durations during the growing season.	1. Algae in pore spaces, 2. Films on ped faces, or 3. Soil compacted or replaced by substrate with negligible pore space.	0.1
	Soil saturated to surface or ponded throughout the year.	Soil compacted or replaced by substrate with negligible pore space.	0.0
V_{WTF}: Fluctuation of water table	Range of water table fluctuation between 75% and 125% of reference standard.	Example: Water table falls rapidly to 15-30 cm of surface	1.0
	Range of water table fluctuation between 25% and 75% or >125% of reference standard.	Water table falls slowly and/or to a depth of 15 cm.	0.5
	Range of water table fluctuation between 0% and 25% of reference standard.	Soils stay nearly saturated or fluctuate within a few cm of the surface over several days to a week.	0.1
	Static water tables or water tables much deeper than reference standard.	Soil saturated to surface throughout the year or water table at 30 cm or greater for long periods.	0.0

$$\textit{Index of Function} = (V_{PORE} + V_{WTF})/2$$

Moderation of Groundwater Flow or Discharge

Definition

Capacity of a wetland to moderate the rate of groundwater flow or discharge from upgradient sources.

Discussion of function and rationale

Riverine wetlands usually form along low-gradient reaches of streams, resulting in relatively low rates of subsurface flow through the wetland. Subsurface flows, both unsaturated and saturated (groundwater), are important linkages between uplands, wetlands, and streams (see for example Roulet 1990 and O'Brian 1980). This is best illustrated by considering Darcy's Law, which states that velocity (V) is equal to the conductivity (K) times the hydraulic gradient (dH/dL). For a saturated K, a reduction in gradient results in a proportional reduction in V. Subsurface water flowing into the wetland from upland, riparian sources, and upgradient in the riverine system (floodplain) encounters a lower gradient and, often, a reduced conductivity as well. The combination of these physical characteristics moderates the flow of water into, through, and out of the wetland. This moderation of flow is usually manifested in prolonged soil wetness in the wetland, more uniform discharges to base flow, and maintenance of seasonal low flows. This function is also manifested in the same way by moderating discharge of groundwater from the wetland resulting from direct precipitation or overbank flows.

Moderation of subsurface flow into the wetland is also important to other functions as well. Studies have shown how wetland/riparian systems serve as sinks for nutrients and contaminants from upland sources (Lowrance et al. 1984). This process results in removal of imported elements and compounds and improved water quality downstream.

Reductions in gradient and/or conductivity are often apparent at the riparian edge of many wetlands where subsurface seepage discharges to the surface at the break in slope. This source area flow often is a major source of stormflow (Dunne and Black 1970, Nutter 1973), and wetlands serve to moderate both timing and volume of storm discharge to the stream. In many riverine wetland systems, the source area flow sustains wetland functions later in the growing season when evapotranspiration rates are high and water from early growing season precipitation and/or overbank flows has been depleted.

Warmer subsurface water feeding the wetland in late fall or early spring sustains or creates warmer soil temperatures which result in a longer season for biological activity and other wetland functions.

Description of variables

V_{SUBIN}, ***Subsurface flow into wetland.*** Subsurface flow into a riverine wetland is often revealed by soil saturation maintained by seeps along the break in slope at the wetland edge. Other evidence is the slow drainage of water from the wetland after a precipitation or flooding event and the positive upward flow indicated by springs or piezometers installed in the wetland. Extreme low-conductivity clays and coarse sands have little impact on flow of groundwater for opposite reasons. Tight clays with very low conductivities do not transmit water readily, particularly under the conditions of low hydraulic head common in many riverine wetlands. Conversely, coarse sands with very high conductivities do not moderate flow significantly because of their high flow-through rates.

The relationship between channel depth and distance to edge of wetland defines the slope of hydraulic gradient from wetland to channel. This gradient will determine the rate of discharge from a riverine floodplain wetland to its stream. Different fractional distances may be appropriate for specific subclasses and combinations of soil permeability, gradients, and stratigraphy.

The determination of subsurface flow conditions is difficult because they cannot be seen directly. Scaling the index of the variable in comparison with the reference standard requires careful selection of the reference domain and placement of the wetland class in the proper hydrogeomorphic subclass.

A reference standard determined by indirect methods is presented here as an example. Careful selection of the indicators directly related to site conditions is necessary to establish the reference standard. It may be necessary to establish a monitoring network of piezometers in a representative reference wetland to understand the nature of these variables. Decreasing evidence or diminishing of the variable requires a reduction in the index.

V_{SUBOUT}, ***Subsurface flow from wetland to aquifer or to base flow.*** Rate of discharge of groundwater from the wetland is controlled by, among other things, the supply of water into the wetland (V_{SUBIN}) and hydraulic head gradients to the point of discharge. Other than losses to evapotranspiration, most riverine wetlands lose water as base flow to the stream, as subsurface stormflow, or as recharge to an underlying aquifer. The presence of underlying impeding layers may shunt more flow to the stream. Absence of such a layer may promote a greater portion of discharge to an underlying aquifer, particularly if the soils are of moderate to high permeability.

The average base flow stage in an adjacent stream influences the water table gradient in a floodplain wetland, much like a drainage ditch dug in an agricultural field. Incised streams with a low base flow stage would result in a higher gradient on the water table next to the stream and a higher rate of discharge than a stream not deeply incised or with average base flow stage near the wetland surface.

Flow from the wetland groundwater system is characterized by a negative downward gradient. Direct observation of this must be by piezometer or by comparing groundwater and streamflow measurements during base flow periods. Both methods are difficult, costly, and time consuming. Ruddy (1989) describes one possible approach to measuring groundwater gradients. Indirect observations are usually necessary to make comparisons to the reference standard of the same hydrogeomorphic subclass. Permeable soils underlain by somewhat permeable underlying layers should score 1.0. Where underlying horizons or strata are less permeable and/or gradients become less steep due to alterations of water tables, the score should be scaled downward. A zero score should be assigned if there is no direct connection to a stream or aquifer due to extreme water table alteration.

Index of function

The model is the sum of the variables that describe the input of subsurface water (V_{SUBIN}) and the discharge of subsurface water (V_{SUBOUT}). The model is

$$Index\ of\ Function = (V_{SUBIN} + V_{SUBOUT})/2$$

It is assumed that these two variables are of equal importance in the reference standard.

Documentation

MODERATION OF GROUNDWATER FLOW OR DISCHARGE

Definition: Capacity for wetland to moderate the rate of groundwater flow or discharge from upgradient sources.

Effects Onsite: Prolonged wetness/saturated soil conditions; extended growing season; moderate soil temperatures.

Effects Offsite: Maintains upgradient or upslope groundwater storage, base flow, seasonal flow regimes, surface water temperature.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{SUBIN}: Subsurface flow into wetland	1. Groundwater discharge measured in seeps or springs and discharge from wetland or 2. Positive (upward) groundwater gradient measured by piezometers; scored relative to reference standard.	Example of the reference standard determined by regional standards: 1. Seeps present at edge of wetland or 2. Vegetation growing during dormant season or drought (i.e., wet soils support vegetation) or 3. Wetland occurs at toe of slope or 4. Artesian flow (upwelling) on wetland surface.	1.0
		Regional standards greatly reduced.	0.5
		Regional standards absent with potential for recovery.	0.1
		Regional standards absent with no potential for recovery.	0.0
V_{SUBOUT}: Subsurface flow from wetland to aquifer or to base flow	Negative (downward) groundwater gradient measured by piezometers; score relative to reference standard.	Example of the reference standard determined by regional standards: 1. Sandy soils without underlying impeding layer or 2. Permeable underlying stratigraphy.	1.0

V_{SUBOUT}: (Concluded)		Regional standards greatly reduced.	0.5
		Regional standards absent with potential for recovery.	0.1
		Regional standards absent with no potential for recovery.	0.0

$$Index\ of\ Function = (V_{SUBIN} + V_{SUBOUT})/2$$

Nutrient Cycling

Definition

Abiotic and biotic processes that convert nutrients and other elements from one form to another; primarily recycling processes.

Discussion of function and rationale

Cycling of nutrients (including nonessential elements) is a fundamental ecosystem process. Nutrient cycling is mediated by two variables: net primary productivity, in which nutrients are taken up by plants, and detritus turnover, in which nutrients are released for renewed uptake by plants, thus completing a cycle. In performing this function, wetlands can maintain standing stocks of nutrients sufficient to support a level of net primary production and detrital turnover typical of ambient climatic and edaphic conditions. In general, fertile sites (i.e., those that are nutrient-rich) have higher levels of annual net primary production and nutrient uptake than infertile ones. Controls on detritus turnover, especially of large woody components and humus, have not been as well established or as widely recognized (Boddy 1983).

Because this function involves some of the most conspicuous components of ecosystems (living plants and dead plant material), its variables have been well studied and documented. There is a rich literature in ecology and forestry that reports estimates of biomass and aerial net primary productivity (ANPP) for mature and successional stages of many forested wetlands (reviewed in Brinson 1990). Detrital turnover of large woody components is less frequently measured, but decay rates of annual leaf-fall are well documented. It is well established that most recycling occurs through the breakdown of organic matter in detrital pathways, not grazing ones (Brinson, Lugo, and Brown 1981).

The full suite of elements that becomes transformed between oxidized and reduced conditions is the essence of this function. Further, the recycling of nutrients in a wetland ecosystem does more to maintain a favorable biogeochemistry (i.e., good water quality) than relatively permanent removal of inflowing nutrients and other elements by wetlands. While the foregoing sentence may overstate the case in some wetlands, imagine the capacity of a wetland to remove nutrients that has neither ANPP nor detrital turnover. Further, without the return of nutrients from detritus, ecosystems would quickly become depleted of nutrients and their primary production would decrease. In short, the function is responsible for maintaining living biomass and detrital stocks. Without a rough balance between uptake and turnover, a much lower rate for one of the two processes could limit the other.

Nutrient cycling can be contrasted with the Removal of Imported Elements and Compounds function which evaluates wetlands as elemental sinks. Most relatively intact and unpolluted riverine wetlands, however, do not substantially reduce the concentration of inorganic nitrogen, phosphorus, or other constituents downstream unless loading rates are well above background. This is because considerable recycling occurs such that uptake and release are in relatively close balance (Finn 1980). This recycling is critical to maintaining low concentrations of elements and nutrients in flowing water (Elder 1985). The concept is similar to nutrient spiraling in streams (Elwood et al. 1983). Specific nutrients or elements are not singled out for this function. In situations where more detailed assessment of nutrient-related functions is desirable, the cycles of elements such as nitrogen and phosphorus could be assessed separately.

Description of variables

Nutrient Cycling can be estimated in several ways. One way would be to directly measure litterfall, stemflow, canopy throughflow, and net biomass production, multiply each of the flows by the concentration of a particular nutrient, and appropriately aggregate the flows over time, usually 1 year. A similar approach could be taken for nutrient release from detritus. These would all be direct measures requiring considerable effort and time.

The function can be approached logically. If living and detrital biomass are distributed in a wetland being assessed in the same proportions and quantities as occur at reference standard sites, it is unlikely that the cycling of nutrients could differ significantly between the two conditions. One way of estimating living and dead biomass is to estimate biomass or cover of vegetation, and the volume or cover of detritus. Each of these components is related as variables to reference standards and appropriately aggregated into the variables used for the index of function. This is the approach used for wet pine flats in North Carolina (Brinson and Rheinhardt, in press). The variables discussed below are only aerial net primary productivity and annual turnover of detritus rather than the more detailed measurements described in Brinson and Rheinhardt (in press).

V_{PROD}, Aerial net primary productivity. Aerial net primary productivity (ANPP) is one of two variables for the function that can be directly measured. The great amount of effort required to do this is impractical for rapid assessment. Instead, ANPP can be indirectly estimated from estimates of leaf area, or leaf area index (as determined from interception of incoming solar radiation). Other components of ANPP have been estimated in some forested wetlands from the relationships between age, basal area, and biomass for developing stands (Mengel and Lea 1990). We assume that the presence of living biomass is an indicator that nutrient uptake processes are occurring. Standing stocks of trees, density or cover of shrubs, and herbaceous plant cover could be measured or estimated as a substitute for primary production (e.g., V_{BTREE}, V_{SHRUB}, V_{HERB}).

The ANPP can be estimated from regressions between growth and age-dependent stand characteristics, and measures of annual litterfall. If one can assume that these indices and measures are proportional to the V_{PROD}, a continuous scale may be used to estimate the variable relative to the reference standard score of 1.0, and 0.0 as the endpoint in the absence of living biomass. Otherwise, categorical variables may be assigned using 1.0 for 75 to 125 percent of reference standard, 0.5 for 25 to 75 percent or > 125 percent of reference standard, 0.1 for 0 to 25 percent of reference standard, or zero for the absence of variables and indicators. If the forest has recently been cleared, but has potential for recovery, it may be scored 0.1. This recognizes that root stock and seed banks may be viable, so the distinction can be made between a site that has potential for recovery and one that has received an irreversible alteration. If the area is essentially barren and is not being managed for recovery, no credit is given. Open patches due to canopy gap dynamics (Pickett and White 1985) should not be construed as a lack of ANPP, but rather a common condition of relatively mature forest stands (see V_{PATCH} and V_{GAPS} in section Maintain Spatial Structure of Habitat).

V_{TURNOV}, Annual turnover of detritus. Detritus turnover is "the other half" of nutrient cycling. Detrital stocks are represented by snags, down and dead woody debris, organic debris on the forest floor (leaf litter, fermentation, and humus layers), and organic components of mineral soil. It is assumed that detritus standing stocks are proportional to detritus turnover. Standing stocks of detrital biomass (V_{SNAG}, V_{CWD}, V_{FWD}) can be substituted for turnover.

Most detrital components can be observed directly and compared with reference standards. Additional indicators could include fungi and mycorrhizae, as well as arthropods and other invertebrates, for assessments conducted in more detail.

Sites within 75 to 125 percent of reference standards in detrital stocks score 1.0. Where detrital stocks are significantly reduced (25 to 75 percent) or overabundant (> 125 percent), the variable should score 0.5; if major disturbance has depleted the site of most soil and detrital organic matter (1 to

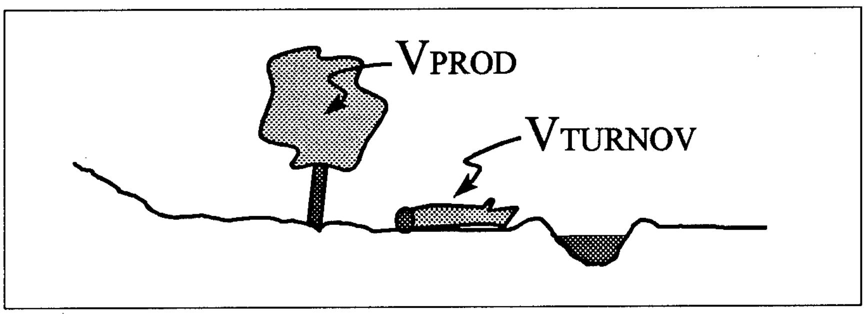
25 percent), the function should receive a 0.1. If there are no detrital stocks and the potential for recovery is absent, the score should be zero.

Index of function

Aerial net primary productivity (V_{PROD}) and annual detritus turnover (V_{TURNOV}) are the variables that model the Nutrient Cycling function. Because of the interdependency of the two processes, the level of functioning is determined by the lesser of the two in comparison with reference standards. The reference standard for this function is a level of ANPP and decomposition, roughly in balance with one another, that is required to sustain living biomass and detrital stocks.

$$\textit{Index of Function} = \textit{If } V_{PROD} > V_{TURNOV}, \textit{ then index is } V_{TURNOV}; \textit{ otherwise, } V_{PROD}$$

If one of the variables is lacking, the function does not occur in a sustainable fashion in the sense described here.



Documentation

NUTRIENT CYCLING

Definition: Abiotic and biotic processes that convert nutrients and other elements from one form to another; primarily recycling processes.

Effects Onsite: Net effects of recycling are elemental balances between gains through import processes and losses through hydraulic export, efflux to the atmosphere, and long-term retention in persistent biomass and sediments.

Effects Offsite: To the extent that nutrients are held onsite by recycling, they will be less susceptible to export downstream. This reduces the level of nutrient loading offsite.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{PROD}: Aerial net primary productivity	Annual litterfall or living biomass accumulation estimated from stand metrics as a linear relationship between reference standard (1.0) and absent (0.0).	Percent cover of all strata (canopy, subcanopy, shrub, ground cover) between 75% and 125% of reference standard.	1.0
		Percent cover as above, but between 25% and 75% or >125% of reference standard.	0.5
		Leaf area or living biomass between 0% and 25% of reference standard or the site lacks living biomass due to clearing with potential for recovery.	0.1
		No leaf area due to clearing; no potential for recovery.	0.0
V_{TURNOV}: Annual turnover of detritus	Turnover of detritus as a linear relationship between reference standard and zero.	Stocks of detrital and soil organic matter between 75% and 125% of reference standard in terms of: snags, down dead woody debris, leaf litter, fermentation and humus layers, and fungal fruiting bodies.	1.0
		As above, but between 25% and 75% or >125% of reference standard.	0.5
		Stocks of detrital and soil organic matter between 0% and 25% of reference standard, or stocks of detrital and soil organic matter absent with potential for recovery.	0.1
		Area barren; no potential for recovery.	0.0

$$\textit{Index of Function} = \textit{If } V_{PROD} > V_{TURNOV}, \textit{ then index is } V_{TURNOV}; \textit{ otherwise, } V_{PROD}$$

Removal of Imported Elements and Compounds

Definition

The removal of imported nutrients, contaminants, and other elements and compounds.

Discussion of function and rationale

The functioning of wetlands as interceptors of nonpoint source pollution is well documented (reviewed by Johnston 1991). Riverine wetlands, particularly those in headwater positions, are strategically located to intercept nutrients and contaminants before they reach streams (Brinson 1988). We use the term "removal" to imply the relatively long-term accumulation or permanent loss of elements and compounds from incoming water sources. This can be contrasted with the Nutrient Cycling function in which a portion of the elements is recycled on a time frame of one year or less.

This method takes a very broad approach to both the elements and compounds of interest and the mechanisms by which they are removed. This is in contrast to most research on the topic, which is conducted on one element or mechanism at a time. Elements include macronutrients essential to plant growth (nitrogen, phosphorus, potassium, etc.) and other elements such as heavy metals (zinc, chromium, etc.) that can be toxic at high concentrations. Compounds include herbicides, pesticides, and other imported materials. Mechanisms of removal include sorption, sedimentation, denitrification, burial, decomposition to inactive forms, uptake and incorporation into long-lasting woody and long-lived perennial herbaceous biomass, and similar processes.

Within a physiographic region, it may be important to focus on particular elements. For example, one might focus on nitrogen and phosphorus, because of their importance in eutrophication of lakes and streams (Gunterspergen and Stearns 1985; Johnston, Detenbeck, and Niemi 1990). Nitrogen and phosphorus are removed in very different ways because the former is part of a gaseous biogeochemical cycle and the latter a sedimentary cycle (Schlesinger 1991). Both elements may be more or less permanently buried in deeper sediments. However, nitrogen removal occurs primarily by denitrification, which releases nitrogen gases to the atmosphere. Phosphorus, however, is not truly removed. The soluble orthophosphate ion (PO_4^{3-}) may become sorbed to clay and iron particles in the soil. The capacity of soils to sorb phosphorus from solution is largely a function of iron and aluminum content (Richardson 1985), both of which are generally found in abundance in riverine wetlands. Normally most phosphorus is associated with particulate materials that are removed from the water column as sediments settle on the floodplain during flooding. Annual net uptake of phosphorus by growing vegetation, although significant, usually represents a small quantity relative to other soil/sediment sinks of phosphorus (Brinson 1985).

Reviews on nutrient removal by wetlands include those by Faulkner and Richardson (1989) and Johnston (1991). From the mid-1970s to the mid-1980s, much research and development effort was invested in utilizing wetlands as sites for tertiary treatment of wastewaters. Much of the nutrient uptake work is summarized in U.S. Environmental Protection Agency (1983), Godfrey et al. (1985), and Ewel and Odum (1984).

Description of variables

V_{FREQ}, ***Frequency of overbank flow.*** In order for riverine wetlands to remove imported elements and compounds, they must first be transported to a wetland. In riverine wetlands, one of the most common transport mechanisms is overbank flow. Without it, there would be little opportunity for waterborne materials in streams to be removed by biogeochemical processes operating on floodplain wetlands.

Data from stream-gauging stations are reliable for estimating this variable. Few streams have gauges, however, or few have them in locations that would be useful for determining frequency of overbank flow. Other applicable indicators are water marks, silt lines, ice scars, bryophytes and lichens on trunks, drift and wrack lines, sediment scour, and sediment deposition. Many of these simply indicate recent flooding (silt lines) or infrequent events (ice scour) and, therefore, may not be particularly helpful in establishing the flood return interval (inverse of flood frequency) of a particular site.

Indices correspond to flood return intervals, with the maximum condition being 1.0 for the reference standard. If the reference standard is flooding at the 2- to 5-year return interval, a score of 1.0 should be assigned. An annual flood regime would be inappropriate for that site and should score 0.5. Likewise, a return interval longer than 5 years should receive a 0.5. A score of 0.1 could be used for extreme departures of flooding above and below the appropriate return interval. A score of 0.0 should be used to indicate lack of overbank flow.

V_{SURFIN}, ***Surface inflow.*** When precipitation rates exceed soil infiltration rates, overland flow in uplands adjacent to riverine wetlands may become a water source. Indicators include the presence of rills and rearranged litter on an upland leading to a floodplain. Saturated surface flow may also occur as partial area contributions (Dunne and Black 1970). Tributaries leading to the riverine upland and not connected to the main channel contribute channelized surface inflow to the wetland.

V_{SURFIN} can be measured directly, but this is impractical for rapid assessment and methods are fraught with problems. Indirect measures can be made visually. Rills on adjacent slopes and lateral tributaries not connected to the main channel of the wetland can be quantified. Seeps at the toe of upland slopes are indicative of saturated surface inflow from partial area contributions.

The variable score is 1.0 if either of the following indicators is similar to reference standards: rills on adjacent upland slopes, or lateral tributaries entering the floodplain and not connected to the channel. If neither of these indicators is similar to reference standards, and either is less than reference standards, the variable is 0.5. Absence of both indicators scores 0.1, while the presence of ditches at the toe of the slope (which would intercept surface flows) would warrant a score of zero.

V_{SUBIN}, ***Subsurface inflow.*** Another common transport mechanism is subsurface flow, which includes unsaturated flow and groundwater discharge from upslope. If soils of adjacent uplands are porous (sandy), high infiltration rates will minimize overland flow except during extreme precipitation or frozen soil conditions. Groundwater discharge can occur where the base of an upland slope intersects with a floodplain surface. Groundwater may also discharge from below into a floodplain alluvium itself. In either case, a floodplain wetland will have an opportunity to influence water chemistry unless its stream channel has cut into adjacent upland and directly intercepts subsurface inflows. Several studies have documented this process (Peterjohn and Correll 1984, Roulet 1990). For headwater streams lacking well-developed floodplains, this transport mechanism is particularly relevant where there is insufficient channel discharge to cause overbank flow.

Groundwater discharge to a wetland seldom can be observed directly, but base flow in stream channels, saturation to the surface, and seeps at the foot of slopes are indicators that discharge is occurring. Confirmation from piezometer or well data in concert with stream hydrographs are direct measures.

Because of the difficulty in measuring unsaturated lateral flow and groundwater discharge, one normally must rely on indirect methods rather than direct hydrologic measurements. The suggestion for scores of 1.0, 0.5, 0.1, and 0.0 is an attempt to scale along a gradient of decreasing levels of indicators.

V_{MICRO}, ***Microtopographic complexity.*** Many of the nutrient removal and sorption processes are dependent on the water table creating specific soil moisture conditions that facilitate the removal of nutrients (e.g., anoxic or oxidized conditions). No soil condition is conducive for all processes. In fact some conditions promote opposite results (e.g., phosphorus precipitation and removal from the water column under oxic conditions and phosphorus release from sediments and diffusion to the water column under anoxic conditions). For example, phosphate precipitation occurs most readily where conditions are oxic, and iron and aluminum are abundant. Denitrification requires anoxia, but nitrification is carried out by bacteria metabolizing aerobically. Consequently, a varied and complex microtopography will expose water simultaneously to a variety of conditions at any one time.

Measurement of microtopographic complexity is discussed under Dynamic Surface Water Storage. Microtopographic complexity similar to the reference standard scores 1.0. Estimates below reference standard should score 0.5 unless they are virtually absent. Smoothed, graded surfaces should receive 0.1 or 0.0 depending on their potential for recovery.

V_{MICROB}, ***Surfaces for microbial activity.*** Microbial activity removes or renders inactive many chemicals and compounds. Microbes tend to be associated with complex surfaces such as leaf litter, humus and soil particles, and plant surfaces. Complex surfaces provide a platform for growth and reproduction, but the material itself may also be a source of organic matter for metabolism.

These surfaces can be estimated from the litter layer (as percent cover, depth, or biomass), organic matter content of soil, stems and leaves of herbaceous plants, peat layers, and so forth.

Surfaces for microbial activity similar to the reference standard should score 1.0. Estimates below score 0.5 unless they are virtually absent. Absence of such surfaces should receive 0.1 or 0.0 depending on a site's potential for recovery.

V_{SORPT}, ***Sorptive properties of soils.*** Physical and chemical removal of dissolved elements and compounds occurs through complexation, precipitation, and other mechanisms of removal (Kadlec 1985). Phosphorus is the most thoroughly studied element. It has been demonstrated that the extractable aluminum of soils, which tends to be inversely proportional to organic carbon content, correlates strongly with potential for phosphorus removal (Richardson 1985). Actual measurement of extractable aluminum concentrations is beyond the scope of most assessments. Various metals also undergo complexation with soil particles, and ions may be temporarily removed from water by cation and anion exchange sites.

Generally, soils that have fine texture (clays, silts) have greater sorption capacities than those with coarse textures. Organic matter also has sorptive properties, particularly in the chelation of heavy metals. Regardless of the mechanisms involved, a comparison of an assessed site with reference standards is the basis for assigning index scores.

County soils surveys, if field verified, can be used to determine in general and describe specifically soil types found in reference standard sites. This same approach can be used in an assessment process.

Soils with physical properties similar to their reference standard should score 1.0. Those that depart in texture, organic carbon content, and other properties should score 0.5. Major departures (e.g., sand to cobbles, clay to sand) should receive 0.1, while 0.0 should be assigned to surfaces lacking soil or natural substrate (e.g., asphalt, concrete).

V_{BTREE}, ***Tree basal area.*** The capacity of herbaceous plants to remove elements for longer than 1 year is limited to long-lived rhizomes, rootstocks, etc. Woody plants, however, may detain elements for longer than 1 year because they are perennial, and woody parts tend to decompose slowly. Elements that have accumulated in tree trunks may become buried in wetlands after falling. The high organic matter content of many wetland sediments is an indication that recycling through decomposition is slow (often a reflection of anoxic conditions) while low organic matter content in other wetlands generally indicates high recycling rates.

The presence of woody basal area (or biomass) measured directly or indirectly can be used as an indicator of the function. If the plants, as in marshes, are all herbaceous and relatively short lived, this variable should not be used in the equation for this function.

If a forested wetland is considered to be midsuccessional, it could be assigned an index score of 1.0. Alternatively, in the unlikely event that the reference standard's condition is truly at a steady state (e.g., an old-growth forest), earlier successional stages represent a departure from the reference standard and should legitimately score less than 1.0. Only barren sites without potential for recovery should be given a 0.0 score.

Index of function

Variables for the Removal of Imported Elements and Compounds function fall into two categories. The first category consists of hydrologic transport mechanisms that bring nutrients to a wetland. The variables are frequency of overbank flow (V_{FREQ}), and sources from adjacent uplands (V_{SURFIN} and V_{SUBIN}).

In the other category are factors contributing to the removal of elements and compounds. These include transformation by exposure to a variety of microenvironments, microbes, sorption to soil, and uptake by vegetation. Microtopography indicates the extent of vertically stratified microsites (V_{MICRO}). The more that microsites are stratified, the greater are the number of soil conditions to which water will be exposed at any one time, resulting in the simultaneous processes of transformation by microbes (V_{MICROB}) and sorption to soil (V_{SORPT}). Uptake by perennial woody vegetation (V_{BTREE}) is more a property of net biomass accumulation and may be related to the successional status of vegetation.

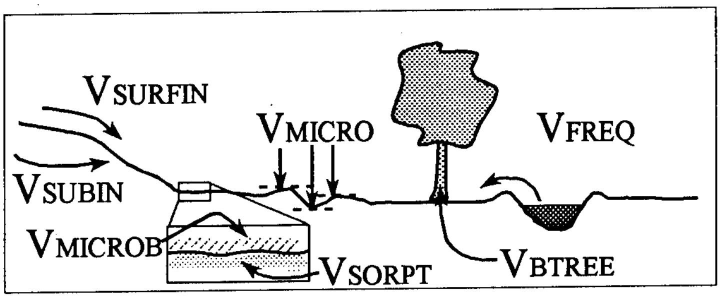
The variables are combined to depict the function in the following manner:

$$\textit{Index of Function} = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN})/3] + [(V_{MICRO} + V_{MICROB} + V_{SORPT})/3] + V_{BTREE}\}/3$$

If the vegetation is normally dominated by short-lived herbaceous species (marshes), then V_{BTREE} should not be used. Therefore,

$$\textit{Index of Function} = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN})/3] + [(V_{MICRO} + V_{MICROB} + V_{SORPT})/3]\}/2$$

It is assumed that the three groups of variables, water sources, soil properties, and uptake by vegetation, are equally important in maintaining the function at this reference standard condition.



Documentation

REMOVAL OF IMPORTED ELEMENTS AND COMPOUNDS

Definition: The removal of imported nutrients, contaminants, and other elements and compounds.

Effects Onsite: Nutrients and contaminants in surface or ground water that come in contact with sediments are either removed from a site or rendered "noncontaminating" because they are broken down into innocuous and biogeochemically inactive forms.

Effects Offsite: Chemical constituents removed and concentrated in wetlands, regardless of source, reduce downstream loading.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{FREQ}: Frequency of overbank flow	Gauge data (1.5) yr return interval similar to reference standard. (Interval in parentheses must be adjusted to reference standard.)	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0
	Gauge data (>2 or <1) yr return interval.	As above, but somewhat greater or less than that of reference standard.	0.5
	Gauge data show extreme departure from reference standard.	Above indicators absent but related indicators suggest overbank flow may occur.	0.1
	Gauge data indicate no flooding from overbank flow.	Indicators absent and/or there is evidence of alteration affecting variable.	0.0
V_{SURFIN}: Surface inflow to the wetland	Use of data from runoff collectors as a continuous variable from reference standard (1.0) to absent (0.0).	Any of the following indicators similar to reference standard: 1. Rills on adjacent upland slopes. 2. Lateral tributaries entering floodplain and not connected to the channel.	1.0

V_{SURFIN}: (Concluded)		Neither of the above indicators similar to reference standards, and either of the above indicators less than the reference standard.	0.5
		Absence of both of the above indicators.	0.1
		Absence of both of the above indicators and hydraulic gradient reversed by regional cone of depression or channelization across wetland and ditches at toe of slope.	0.0
V_{SUBIN}: Subsurface flow into wetland	1. Groundwater discharge measured in seeps or springs and discharge from wetland or 2. Positive (upward) groundwater gradient measured by piezometers and scored relative to reference standard.	Example of the reference standard determined by regional standards: 1. Seeps present at edge of wetland or 2. Vegetation growing during dormant season or drought (i.e., wet soils support vegetation) or 3. Wetland occurs at toe of slope or 4. Artesian flow (upwelling) on wetland surface.	1.0
		Regional standards greatly reduced.	0.5
		Regional standards absent with potential for recovery.	0.1
		Regional standards absent with no potential for recovery.	0.0
V_{MICRO}: Microtopographic complexity	Microtopographic complexity (MC) measured (surveyed) shows MC >75% to <125% of reference standard.	Visual estimate indicates that microtopographic complexity (MC) is >75% to <125% of reference standard.	1.0
	Measured MC is between 25% and 75% that of reference standard.	Visual assessment confirms MC is somewhat less than reference standard.	0.5
	Measured MC is between 0% and 25% that of reference standard; restoration possible.	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1
	No MC at assessed site or natural substrate replaced by artificial surface.	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0
V_{MICROB}: Surfaces for microbial activity	Mass of litter layer measured as a continuous variable between reference standard (1.0) and absent (0.0).	Indicators similar to reference standard, i.e., litter layer, humus stratum, woody debris, and floating, submerged, and herbaceous emergents.	1.0
		As above, but indicators less than reference standards.	0.5

V_{MICROB}: (Concluded)		Indicators absent, with potential for recovery.	0.1
		Indicators absent, without potential for recovery.	0.0
V_{SORPT}: Sorptive properties of soils	Cation exchange capacity and percent base saturation similar to reference standard.	Physical properties of soils similar to the reference standard.	1.0
	As above, but less than reference standard.	Soil departs in texture, organic carbon content, and other properties.	0.5
	As above, but greatly reduced from reference standard.	Major departures (e.g., sand to cobbles, clay to sand).	0.1
	Soil absent; replaced by nonsoil surfaces.	Surfaces lacking soil or natural substrate (e.g., asphalt, concrete).	0.0
V_{BTREE}: Tree basal area	Basal area is greater than 75% of reference standard.	Stage of succession similar to reference standard.	1.0
	Basal area between 25% and 75% of reference standard.	Stage of succession departs significantly from reference standard.	0.5
	Basal area between 0% and 25% of reference standard; restoration possible.	Stage of succession at extreme departure from reference standard.	0.1
	No trees present; restoration not possible.	Stand cleared without potential for recovery.	0.0

$$\begin{aligned} \textit{Index of Function} = \{ & [(V_{FREQ} + V_{SURFIN} + V_{SUBIN})/3] \\ & + [(V_{MICRO} + V_{MICROB} + V_{SORPT})/3] \\ & + V_{BTREE}\}/3 \end{aligned}$$

If the vegetation is normally dominated by short-lived herbaceous species (marshes), then V_{BTREE} should not be used. Therefore,

$$\begin{aligned} \textit{Index of Function} = \{ & [(V_{FREQ} + V_{SURFIN} + V_{SUBIN})/3] \\ & + [(V_{MICRO} + V_{MICROB} + V_{SORPT})/3]\}/2 \end{aligned}$$

It is assumed that the three groups of variables, water sources, soil properties, and uptake by vegetation, are equally important in maintaining the Removal of Imported Elements and Compounds function at the reference standard.

Retention of Particulates

Definition

Deposition and retention of inorganic and organic particulates ($>0.45\ \mu m$) from the water column, primarily through physical processes.

Discussion of function and rationale

Flooding from overbank flow of alluvial streams is a major source of inorganic particulates for floodplain wetlands. Floodplains of smaller streams also receive sediments due to overland flow from adjacent uplands. Once waterborne sediment has been transported to a floodplain, velocity reduction normally occurs due to surface roughness and increasing cross-sectional area of discharge (Nutter and Gaskin 1989). This leads to a reduction in the capacity of water to transport suspended sediments, so particulates settle. The best evidence of this function is the presence of retained sediments in depositional layers. This evidence is particularly diagnostic when deposition is recent and can be related to a specific flood event.

Retention applies to particulates arising from both onsite and offsite sources, but excludes in situ production of peat. The Retention of Particulates function contrasts with Nutrient Cycling and Removal of Imported Elements and Compounds because the emphasis is more dependent on physical processes (e.g., sedimentation and particulate removal). Sediment retention occurs through burial and chemical precipitation (e.g., removal of phosphorus by Fe^{3+}). Dissolved forms may be transported as particles after undergoing sorption and chelation (i.e., heavy metals mobilized with humic and fulvic compounds). Imported sediment can undergo renewed pedogenesis on site, which potentially involves weathering and release of elements that were previously inaccessible to mineral cycling.

The same hydrodynamics that facilitate sedimentation may also capture and retain existing organic particulates. For example, deposition of silt by winter floods following autumn litterfall appears to reduce the potential for leaves to become suspended by currents and exported (Brinson 1977).

Because sources of water and depth of flooding vary greatly among stream orders (Brinson 1993b), there may be a need to stratify subclasses by stream order to reduce this natural source of variation. Headwater streams that accumulate large amounts of sediments may represent a disturbed condition incapable of sustaining the function. Excessive retention of particulates, as in reservoirs, may create a "sediment shadow" downstream from the dam (Rood and Mahoney 1990). Consequently, unusually high or low depositional rates in such areas should not receive the highest functional index score. In addition, such sites should not be used to determine reference standards.

Description of variables

V_{FREQ}, ***Frequency of overbank flow***. Sediments must be transported to the wetland surface in order for them to be removed. In riverine wetlands, one of the most common transport mechanisms is overbank flow. Without it, there would be little opportunity for fine suspended sediments in streams to be removed by floodplain wetlands.

Data from stream-gauging stations are reliable for estimating this variable, but not all streams have gauges. Other applicable indicators are water marks, silt lines, ice scars, bryophytes and lichens on trunks, drift and wrack lines, sediment scour, and sediment deposition. Many of these simply indicate recent flooding (silt lines) or an infrequent event (ice scour), and therefore may not be particularly helpful in establishing the flood return interval (inverse of flood frequency) of a particular site.

Indices correspond to flood return intervals, with the maximum condition being 1.0 for the reference standard. If reference standard sites flood at a 2- to 5-year return interval, an unaltered condition in an assessed wetland site with a 2- to 5-year return interval would score 1.0. In contrast, if the site were altered to have an annual flood regime or a return interval of >5 years, a score of 1.0 would be inappropriate for such a site and it should score less than 1.0. A score of 0.1 would be used for large departures above and below the return interval for the reference standard. A score of zero should be used to indicate lack of overbank flow.

V_{SURFIN}, ***Surface inflow***. Overland flow from uplands to the wetland surface can transport sediments to the wetland surface. If soils of adjacent uplands are porous (sandy), high infiltration rates will probably eliminate overland flow except during extreme precipitation or frozen soil conditions.

Surface inflow may be indicated by rills along the upland slope leading to a floodplain. If wetlands are relatively undisturbed, there should be little surface inflow. Lateral tributaries entering a floodplain and not connected to the main channel would also qualify as a surface inflow. The variable score is 1.0 if either of the following indicators is similar to reference standards: rills on adjacent upland slopes, or lateral tributaries entering the floodplain and not connected to the channel. If neither of the above indicators is similar to reference standards, and either is less than reference standards, the variable is 0.5. Absence of both indicators scores 0.1, while the presence of ditches at the toe of the slope (which would intercept surface flows) would warrant a score of zero.

V_{HERB}, V_{SHRUB}, V_{BTREE}, V_{DTREE}, V_{MICRO}, V_{CWD}, ***Roughness factors***. The six roughness factors are roughness due to herbaceous plants (V_{HERB}), roughness due to shrubs (V_{SHRUB}), roughness due to tree basal area (V_{BTREE}), roughness due to tree density (V_{DTREE}), roughness due to microtopographic complexity (V_{MICRO}), and roughness due to coarse woody debris (V_{CWD}). As water flows over surfaces, friction and shear forces create turbulent flow and reduce velocities, both of which are conducive to sediment deposition. The four variables are scaled independently. However, Manning's coefficients have been developed for site-specific data to attempt to provide quantitative relationships between roughness and wetland structure (Arcement and Schneider 1989). This coefficient integrates all variables of roughness which, if information were available, would allow the collapsing of V_{HERB} through V_{CWD} into one variable.

Each of the roughness components should be evaluated separately unless there are available guidelines for Manning's n. Roughness similar to the reference standard should receive a score of 1.0. Estimates below reference standard should score 0.5 unless roughness is virtually absent. Smoothed, graded surfaces should receive 0.1 or zero depending on a site's potential for recovery.

V_{SEDIM}, ***Retained sediments***. Sophisticated techniques are available for determining quantitative rates of sedimentation (i.e., cesium-137 mass balances; Cooper and Gilliam 1987). These techniques are too time consuming for the rapid assessment used in the HGM approach.

Qualitative evidence of retained sediments may be indicated by layers of leaves buried under sediment layers, but such rates of deposition are infrequent in most undisturbed and small watersheds. Another indicator of sediment deposition in riverine wetlands is the presence of natural levees formed by overbank flow. Coarse sediments settle on streambanks during floods, thus contributing to levee formation, while finer sediments escape sedimentation until they are carried into more quiescent parts of the floodplain.

Deposition similar to the reference standard scores 1.0. Deposition below the reference standard should receive a score of 0.5 unless deposition is virtually absent. Deposits that greatly exceed the reference standard or absence of sediments should receive 0.1. If hydrologic alterations eliminate this variable, a score of zero should be assigned.

Index of function

The variables used in the Retention of Particulates function are frequency of overbank flow (V_{FREQ}), surface inflow (V_{SURFIN}), roughness of wetland surfaces (V_{HERB}, V_{SHRUB}, V_{BTREE}, V_{DTREE}, V_{MICRO}, V_{CWD}), and evidence of retained sediments (V_{SEDIM}). In small streams where overbank flow seldom occurs due to the headwater position, a potential source of sediments would be from uplands as particulates transported in overland flow. Most headwater streams are erosional, however, and relatively undisturbed uplands do not serve as a substantial source of sediments. When uplands are disturbed and begin to release sediments, headwater streams may become depositional (Cooper and Gilliam 1987). This is possibly a function of an altered landscape and must be dealt with in the context of a specific reference domain.

The variables depict the function in the following manner:

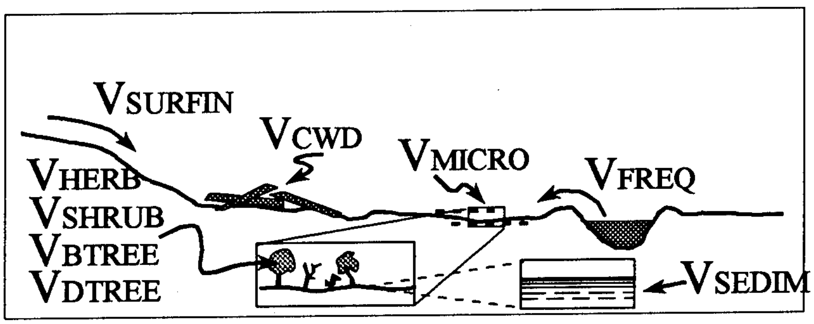
First option:

$$Index\ of\ Function = \{[(V_{FREQ} + V_{SURFIN})/2] \times [(V_{HERB} + V_{SHRUB} + V_{BTREE} + V_{DTREE} + V_{MICRO} + V_{CWD})/6]\}^{1/2}$$

Second option if data or indicators are available:

$$Index = V_{SEDIM}$$

It is assumed that the transport group of variables and roughness factors are equally important in maintaining the function under reference standards condition.



Documentation

RETENTION OF PARTICULATES

Definition: Deposition and retention of inorganic and organic particulates (>0.45 μm) from the water column, primarily through physical processes.

Effects Onsite: Sediment accumulation contributes to the nutrient capital of an ecosystem. Deposition increases surface elevation and changes topographic complexity. Organic matter may also be retained for decomposition, nutrient recycling, and detrital food web support.

Effects Offsite: Reduces stream sediment load and entrained woody debris that would otherwise be transported downstream.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{FREQ}: Frequency of overbank flow	Gauge data (1.5) yr return interval; similar to reference standard. (Intervals in parentheses must be adjusted to the reference standard.)	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0
	Gauge data (>2 or <1) yr return interval; departure from reference standard.	As above, but somewhat greater or less than that of reference standard.	0.5
	Gauge data show extreme departure from reference standard.	Above indicators absent but related indicators suggest overbank flow may occur.	0.1
	Gauge data indicate no flooding from overbank flow.	Indicators absent and/or there is evidence of alteration affecting variable.	0.0
V_{SURFIN}: Surface Inflow to the wetland	Use of data from runoff collectors as a continuous variable from reference standard (1.0) to absent (0.0).	Any of the following indicators similar to reference standard: 1. Rills on adjacent upland slopes. 2. Lateral tributaries entering floodplain and not connected to the channel.	1.0
		Both of the above indicators similar to reference standards, and any of the above indicators less than the reference standard.	0.5
		Absence of both of the above indicators.	0.1
		Absence of both of the above indicators, and channelization across wetland prevents sedimentation on wetland surface.	0.0
V_{HERB}: Herbaceous plant density, biomass, or cover	Herbaceous density, biomass or cover scaled as a linear function of reference standard ranging from 1.0 to 0.0	Herbaceous plant cover between 75% and 125% that of reference standard.	1.0
		Herbaceous plant cover between 25% and 75%, or more than 125% that of reference standard.	0.5
		Herbaceous plant cover between 0% and 25% that of reference standard.	0.1

V_{HERB}: (Concluded)		Herbaceous plant cover absent; restoration not possible.	0.0
V_{SHRUB}: Shrub and sapling density, biomass, or cover	Shrub abundance >75% that of reference standard.	Visual estimate of shrubs and saplings indicates site is similar (>75%) to reference standard.	1.0
	Shrub abundance between 25% and 75% that of reference standard.	Visual estimate of shrubs and saplings indicates site is between 25% and 75% that of reference standard.	0.5
	Shrub abundance between 0% and 25% that of reference standard.	Shrubs and saplings sparse or absent relative to reference standard; restoration possible.	0.1
	Shrubs absent; restoration not possible.	Shrubs and saplings absent; restoration not possible.	0
V_{BTREE}: Tree basal area	Basal area or biomass is greater than 75% of reference standard.	Stage of succession similar to reference standard.	1.0
	Basal area or biomass between 25% and 75% of reference standard.	Stage of succession departs significantly from reference standard.	0.5
	Basal area or biomass between 0% and 25% of reference standard; restoration possible.	Stage of succession at extreme departure from reference standard; restoration possible.	0.1
	No trees are present; restoration not possible.	Stand cleared; no restoration possible.	0
V_{DTREE}: Tree density	Measured or estimated tree density is between 75% and 125% of reference standard.	Stage of succession similar to reference standard.	1.0
	Tree density is between 25% and 75%, or between 125% and 200%, of reference standard.	Stage of succession departs significantly from reference standard.	0.5
	Tree density is between 0% and 25%, or greater than 200%, of reference standard; restoration possible.	Stage of succession at extreme departure from reference standard; restoration possible.	0.1
	No trees are present; restoration not possible.	Stand cleared; no restoration possible.	0.0
V_{MICRO}: Microtopographic complexity	Microtopographic complexity (MC) measured (surveyed) shows MC >75% and <125% of reference standard.	Visual estimate indicates that microtopographic complexity (MC) is >75% and <125% of reference standard.	1.0

V_{MICRO}: (Concluded)	Measured MC is between 25% and 75% that of reference standard.	Visual assessment confirms MC is somewhat less than reference standard.	0.5
	Measured MC between 0% and 25% that of reference standard; restoration possible.	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1
	No MC at assessed site or natural substrate replaced by artificial surface; restoration not possible.	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0
V_{CWD}: Coarse woody debris (CWD)	Biomass of CWD >75% and <125% that of reference standard.	Volume of CWD is >75% and <125% that of reference standard.	1.0
	Biomass of CWD between 25% and 75% that of reference standard.	Volume of CWD is between 25% and 75% that of reference standard.	0.5
	Biomass of CWD between 0% and 25% that of reference standard; restoration possible.	Volume of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1
	No CWD present; restoration not possible.	No CWD present; restoration not possible.	0.0
V_{SEDIM}: Retained sediments	Accumulation rates using cesium-137, lead-210, feldspar clay layer, scaled as a linear function from reference standard (1.0) to absent (0.0).	Silt or sediment layering on surfaces or buried root collars or natural levees between 75% and 125% of reference standard.	1.0
		As above, but between 25% and 75%, or >125%, of reference standard.	0.5
		As above, but between 0% and 25%, of reference standard.	0.1
		Hydrologic alterations eliminate variable; restoration not possible.	0.0

Option 1:

$$\textit{Index of Function} = \{[(V_{FREQ} + V_{SURFIN})/2] \times [(V_{HERB} + V_{SHRUB} + V_{BTREE} + V_{DTREE} + V_{MICRO} + V_{CWD})/6]\}^{1/2}$$

Option 2:

$$Index = V_{SEDIM}$$

Organic Carbon Export

Definition

Export of dissolved and particulate organic carbon from a wetland. Mechanisms include leaching, flushing, displacement, and erosion.

Discussion of function and rationale

Wetlands export organic carbon at higher rates per unit area than terrestrial ecosystems (Mulholland and Kuenzler 1979) in part because surface water has greater contact time with organic matter in litter and surface soil. While the molecular structure of most of organic matter is not well known because of its chemical complexity (Stumm and Morgan 1981), organic matter nevertheless plays important roles in geochemical and food web dynamics. For example, organic carbon complexes with a number of relatively immobile metallic ions which facilitates transport in soil (Schiff et al. 1990). Organic carbon is a primary source of energy for microbial food webs (Dahm 1981; Edwards 1987; Edwards and Meyer 1986) which form the base of the detrital food web in aquatic ecosystems. These factors, in combination with the proximity of wetlands to aquatic ecosystems, make wetlands critical sites for supplying both dissolved and particulate organic carbon.

Description of variables

V_{FREQ}, ***Frequency of overbank flow***. Overbank flow supplies water to floodplain surfaces. Long contact times of shallow water over large surface areas of organic rich sediments allow organic matter to accumulate in surface waters. However, organic carbon can be exported from floodplains that do not receive overbank flow. Precipitation on riverine wetlands and overland flow from uplands to wetlands can transport water to stream channels for delivery downstream. However, wetlands receiving overbank flow would normally have several orders of magnitude greater water turnover than a wetland without such a water source.

Data from stream-gauging stations are reliable in estimating this variable but not all streams have gauges. Other applicable variables that could be used include water marks, silt lines, ice scars, bryophyte and lichen levels, drift and wrack lines, sediment scour, and sediment deposition. Many of these variables simply indicate that recent flooding (silt lines) may have occurred during an infrequent event (ice scour), and therefore not be particularly helpful in establishing the flood return interval of a particular site.

Indices are related to flood frequencies and a maximum of 1.0 should be given to a site that receives the same flood frequency as its reference standard. Indices for other frequencies are lower and lack of overbank flow should receive a zero.

V_{SURFIN}, ***Surface inflow***. When precipitation rates exceed soil infiltration rates, overland flow in uplands adjacent to riverine wetlands can transport organic carbon, both dissolved (DOC) and particulate (POC), to a wetland surface. Indicators include the presence or rills and rearranged litter on upland slopes leading to the floodplain. Saturated surface flow may also occur as partial area contributions (Dunne and Black 1970). Tributaries leading to a riverine wetland and not connected to the main channel may also transport organic carbon to the wetland being assessed. Even if these sources do not contribute excess organic carbon to a wetland being assessed, these sources would likely displace surface water ponded in the wetland so that export occurs. V_{SURFIN} can be measured directly, but this is impractical for rapid assessment.

Indirect measures are made visually and compared with reference standards. Seeps at the toe of upland slope are indicative of saturated surface inflow from the partial area contributions. Both DOC and POC may be transported from these sites to the wetland.

The variable should score 1.0 if either of the following indicators is similar to reference standards: rills on adjacent upland slopes, or lateral tributaries entering a floodplain and not connected to its channel. If neither of the above indicators is similar to the reference standard, and either is less than its reference standard, the variable should score 0.5. Absence of both indicators should score 0.1, while the presence of ditches at the toe of the slope (which would intercept surface flows) would warrant a score of zero.

V_{SUBIN}, ***Subsurface inflow***. Subsurface flow into a riverine wetland is often revealed by soil saturation maintained by seeps along the break in slope at the wetland edge. Other evidence includes the slow drainage of water from the wetland after precipitation or a flooding event, and a positive upward flow indicated by springs or piezometers. The conductivity of the alluvium relative to the conductivity of recharge areas in the upland will modify rates of transport.

Subsurface inflow contributes to organic carbon export. Displacement of existing soil water within alluvium may create outflow through surface and subsurface pathways to downstream localities.

Direct measures of groundwater movement are time consuming and impractical for rapid assessment. Indirect methods will depend on regional conditions: Examples are the same as provided for V_{SURFIN} in the function Moderation of Groundwater Flow or Discharge.

$V_{SURFCON}$, ***Surface hydraulic connections with channel***. Internal networks of channels are common features on large riverine floodplains. These channels are conduits for overbank flow during periods of high upriver discharge, but also provide pathways for drainage as upriver discharge is reduced. Where natural levees are prominent, as in alluvial river systems, breaks in levees indicate the potential for overbank flow through channels during high upriver discharge. These breaks are normally connected to the channel network in such a manner that drainage continues to occur long after stage height has fallen below bank-full levels.

Aerial photographs taken during the leafless dormant season may provide evidence of channel patterns. If a wetland is large enough, some of these features are apparent on 7.5-minute topographic maps. Otherwise, onsite visual estimates must be made.

Scaling of surface hydraulic connections is absolutely dependent on calibration established by a reference domain. If the quantity of internal channels is similar to the reference standard, the assessment site should receive a score of 1.0. Estimates below the reference standard should score 0.5 unless connections are virtually absent. Apparent absence of connections should receive a 0.1. Known alterations to sever or block connections should receive a score of zero.

V_{ORGAN}, ***Organic matter in wetland***. Both live and dead plant materials are capable of contributing to the organic carbon concentration of exported water (Cuffney 1988). Leaf litter, especially soon after the autumn litterfall peak, contributes large amounts of leachable dissolved organic carbon (DOC) to floodwaters (Brinson 1977). Other detrital sources include woody debris (both coarse and fine) and organic matter in soil. Leaching of plant material during precipitation events results in high concentrations of DOC in throughfall and stemflow (Brinson et al. 1980, Hauer 1989). Surface accumulations of leaves and twigs into debris piles normally represent material redistributed by overland flow. These litter piles then provide a source for transport downstream (Cummins 1974, Dahm 1981). Wintertime flooding may remove surface litter, and transport material to streams or offsite. The importance of woody debris in food web support on floodplains is not as well documented in the Southeast (Hauer and Benke 1991) as it is in the Pacific Northwest.

Indicators of the presence of organic carbon include estimates of living biomass (V_{BTREE}, V_{SHRUB}, V_{HERB}), litter and fine woody debris (V_{FWD}), coarse woody debris (V_{CWD}), and soil organic carbon (not an established variable). Thus, the various components of organic matter could and probably should be determined separately. Measurements of these various organic matter components are discussed in the Nutrient Cycling function.

A score of 1.0 is earned if indicators are equivalent to the reference standard. A zero should be assigned for a site barren of both detritus and living plants with no potential for recovery. Higher resolution of intermediate values could be established based on direct measurements on reference standard sites.

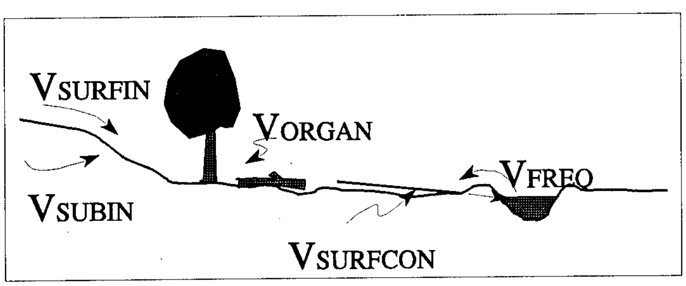
Index of function

Two factors are required for a wetland to be a source of organic carbon for export: a source of organic matter and water flow (a transport mechanism). Water flow has two components - water sources and surface hydraulic connections. The variables used are frequency of overbank flow (V_{FREQ}), and overland flow (V_{SURFIN}) or groundwater discharge (V_{SUBIN}) from adjacent uplands. Surface connections between the wetlands and stream channel ($V_{SURFCON}$) are essential for providing a pathway for return flows to channels, thus assuring that export actually occurs. Normally, if overbank flow occurs, surface connections are present. The fourth variable used is the source of organic matter in a wetland (V_{ORGAN}). One approach is to substitute for V_{ORGAN} all variables that potentially contribute organic carbon for export. These include, in addition to soil organic matter and leaf litter, V_{BTREE}, V_{SHRUB}, V_{HERB}, and V_{CWD} (these variables include both living and dead organic matter). If either organic carbon is absent or surface hydraulic connections are lacking (i.e., the wetland is diked or otherwise isolated), the function is lacking:

$$Index = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN} + V_{SURFCON})/4] \times V_{ORGAN}\}^{1/2}$$

If $V_{ORGAN} = 0$, the function is absent.

It is assumed that in order for the reference standard condition to be sustained, mechanisms of transport and a source of organic carbon are equally important and essential.



Documentation

ORGANIC CARBON EXPORT

Definition: Export of dissolved and particulate organic carbon from a wetland. Mechanisms include leaching, flushing, displacement, and erosion.

Effects Onsite: The removal of organic matter from living biomass, detritus, and soil organic matter contributes to decomposition. Metals may be mobilized by chelation to dissolved and particulate forms of organic carbon.

Effects Offsite: Provides support for aquatic food webs and biogeochemical processing downstream from the wetland.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{FREQ}: Frequency of overbank flow	Gauge data (1.5) yr return interval similar to reference standard. (Interval in parentheses must be adjusted to reference standard.)	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0
	Gauge data (>2 or <1) yr return interval.	As above, but somewhat greater or less than reference standard.	0.5
	Gauge data show extreme departure from reference standard.	Above indicators absent, but related indicators suggest overbank flow may occur.	0.1
	Gauge data indicate no flooding from overbank flow.	Indicators absent and/or there is evidence of alteration affecting variable; restoration not possible.	0.0
V_{SURFIN}: Surface Inflow to a wetland	Use of data from runoff collectors as a continuous variable from reference standard (1.0) to absent (0.0).	Any of the following indicators similar to reference standard: 1. Rills on adjacent upland slopes. 2. Lateral tributaries entering floodplain and not connected to the channel.	1.0
		Neither of the above indicators similar to reference standards, and either of the above indicators less than reference standard.	0.5
		Absence of both of the above indicators.	0.1
		Absence of both of the above indicators, and hydraulic gradient reversed by regional cone of depression, or channelization across wetland prevents inflow.	0.0

V_{SUBIN}: Subsurface flow into wetland	1. Groundwater discharge measured in seeps or springs and discharge from wetland or 2. Positive (upward) groundwater gradient measured by piezometers and scored relative to reference standards.	Example of the reference standard determined by regional standards: 1. Seeps present at edge of wetland or 2. Vegetation growing during dormant season or drought (i.e., wet soils support vegetation) or 3. Wetland occurs at toe of slope or 4. Artesian flow (upwelling) on wetland surface.	1.0
		Regional standards greatly reduced.	0.5
		Regional standards absent with potential for recovery.	0.1
		Regional standards absent with no potential for recovery.	0.0
$V_{SURFCON}$: Surface hydraulic connections	No direct measures.	Visual estimates of internal drainage channels present and connected to main channel between 75% and 125% that of reference standard.	1.0
		As above but between 25% and 75% or >125% that of reference standard.	0.5
		As above, but between 0% and 25% that of reference standard.	0.1
		Internal drainage channels absent or present and blocked from main channel.	0.0
V_{ORGAN}: Organic matter in wetland	Measured standing stocks of live and dead biomass and soil organic matter between 75% and 125% of reference standard.	Visual estimates of litter, coarse woody debris, live woody vegetation, live or dead herbaceous plants, organic rich mineral soils, or histosols at levels between 75% and 125% that of reference standard.	1.0
	As above but between 25% and 75% or >125% of reference standard.	As above but between 25% to 75% or >125% of reference standard	0.5
	As above, but between 0% and 25% of reference standard.'	As above, but between 0% and 25% of reference standard.	0.1
	Standing stocks of live and dead biomass and soil organic matter absent.	No organic matter; no potential for recovery.	0.0

$$Index\ of\ Function = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN} + V_{SURFCON})/4] \times V_{ORGAN}\}^{1/2}$$

Maintain Characteristic Plant Community

Definition

Species composition and physical characteristics of living plant biomass. The emphasis is on the dynamics and structure of the plant com- munity as revealed by the dominant species of trees, shrubs, seedlings, saplings, and ground cover, and by the physical characteristics of vegetation.

Discussion of function and rationale

Vegetation accounts for most of the biomass of riverine wetlands, and the physical characteristics of living and dead plants are closely related to ecosystem functions associated with hydrology, nutrient cycling, and the abundance and diversity of animal species (Gregory et al. 1991). Vegetation is not static, however, and species composition and physical characteristics can change in space and time in response to natural and anthropogenic influences (Shugart 1987).

The importance of plant communities to riverine ecosystems can be understood by considering what happens when vegetation is removed or highly disturbed (Harris and Gosselink 1990). Removal or severe disturbance of riparian vegetation can lead to a change in the structure of macroinvertebrate communities (Hawkins, Murray, and Anderson 1982), a decrease in the species diversity of stream ecosystems, a decline in the local and/or regional diversity of animals associated with riverine corridors, a deterioration of downstream water quality, and a significant change in river/stream hydrology (Gosselink et al. 1990).

The goal of assessing this function is to evaluate species composition and structure of wetland plant communities to determine their successional status relative to their reference standard. If a site being evaluated contains species in various life history stages and in densities that are similar to those found in a mature riparian forest in the same area (i.e., the same wetland hydrogeomorphic class), its plant community is likely to be stable. If a site is dominated by species other than those that are characteristic of mature stands within the area, it is likely that the site has been disturbed by natural or anthropogenic events. If the site has been disturbed, the goal of an assessment is to use species that are present and physical characteristics of the vegetation to determine whether or not the plant community is progressing toward the reference standard.

Description of variables

V_{COMP}, Species composition for tree, sapling, shrub, and ground cover strata. Species composition is one of five variables used to assess the plant community function. Species identifications are relatively easy for most plants, and species lists can be used to compare an assessment site with its reference standard. The highest priority should be given to compilation of a complete species list for each assessment site. A complete species list provides a direct measure of plant species richness of a site and is also valuable in determining whether a site contains any species that are rare, threatened, or endangered. When it is not possible to obtain a complete species list, the most common species in the tree, sapling, shrub, and ground-cover layers should be identified from surveys of the assessment site (direct measure) or from species lists previously compiled for the site (indirect measure).

If three of the dominant species in each of the four strata (tree, sapling, shrub, and ground cover) match three of the four dominants in equivalent strata of reference standard, then the variable should be assigned a 1.0. If only the ground cover does not meet this condition, the site should receive 0.75 for the variable score. The score decreases to 0.5 if neither ground cover nor saplings match three of the four dominants of reference standards. If only the tree stratum shares its three dominants with reference standards, a 0.25 should be assigned to the variable. Finally, if none of the strata meet reference standards, then a score of zero should be assigned. If information is only a variable from an indirect measure (e.g., a species list that has been published or a source of unpublished data), an index score of 1.0 is given only if the species information is verified.

V_{REGEN}, ***Regeneration from seedlings/saplings and/or clonal shoots.*** Death is a natural process in ecosystems (Shugart 1987), and the maintenance of plant communities requires replacement of individuals that die. The understory of a stable plant community typically contains small individuals (saplings/seedlings) of species that occur in the forest canopy. Saplings and seedlings of understory species (shrubs, herbs, and vines) in stable communities will also be present. Species composition of the understory vegetation is, therefore, useful in predicting what a plant community will be like in the future, especially for sites that have been disturbed and are undergoing secondary succession (Sharitz, Schneider, and Lee 1990).

If a direct measure shows that the ratio of sapling and seedling species to canopy species is between 50 and 75 percent of its reference standard (a mature forest), an assessment site has a high probability of being stable and an index of 1.0 should be given for the variable. A score of 0.5 should be given if the measure is 25 to 50 percent of the reference standard; a score of 0.1 should be given if the measure is 0 to 25 percent of the reference standard. If species composition of seedlings or saplings has no similarities with the reference standard sites, or if a site is devoid of vegetation, an index of 0.0 should be given. If information is available only from an indirect measure such as a species list that has been published or obtained from an unpublished source, a score of 1.0 should be given only if such lists are verified. The plant communities of marshes can also be assessed, but without the need to specify strata.

V_{CANOPY}, ***Canopy cover***. Canopy cover is an estimate of spatial continuity in the upper layers of a forest canopy. Many riverine forests possess a relatively continuous canopy, but considerable variation can be expected due to impacts of disturbances from windstorms, floods, and various human activities. Canopy gaps are also present in most mature forests, but these gaps are created by normal mortality processes and should not be considered as a sign of disturbance.

The measurement of canopy cover can be done most simply by making a visual estimate of how much of the sky is covered by leaves when one looks into the canopy. A bottomless cup or cone could be used as a sighting device by pointing it toward the canopy for an estimate of cover. More quantitative methods (analysis of fisheye photographs, measurements of percent light transmission to the forest understory, densitometer measurements) are available, but in most instances they would not be necessary.

If the percent cover in an assessment site is >75 percent of the value established from reference standard sites, a score of 1.0 should given. Index scores of 0.5 and 0.1 should be given when an assessment site and reference standards show 25 to 75 percent and 0 to 25 percent similarity, respectively. A zero is given when there is no tree layer. Indirect measures of percent cover should not be used unless it is impossible to make a direct measure. Recent aerial photographs, taken during the growing season, can be used to provide an indirect measure, but these should be used with great caution as changes may have occurred at the assessment site between the time the evaluation is made and the time the photographs were taken. If data from the indirect measure are verified during a visit to an assessment site, scores should be given using the same ranges as used for direct measures of variables.

V_{DTREE}, ***Tree density***. Density (V_{DTREE}) and basal area (V_{BTREE}, below) of trees can be used to evaluate the successional status and stability of plant communities. As forests mature, tree density decreases and basal area increases until both reach a sustainable level. Tree density and basal area are among the most easily measured variables for forested wetlands, and a large number of publications are available that describe appropriate methods (e.g., Mitsch and Gosselink 1993; Golet et al. 1993; Lugo, Brinson, and Brown 1990). The tree density variable should be used in combination with basal area to provide a robust estimate of forest structure.

If tree density at an assessment site is between 75 and 125 percent of reference standards, it may be assumed that the site is stable and a score of 1.0 should be given. A score of 0.5 should be assigned if the range is either 25 to 75 percent or >125 to 200 percent. Densities beyond the foregoing ranges (i.e., higher or lower) should be assigned 0.1. The absence of tree species receives a zero. Indirect measures of density and basal area should not be used unless it is impossible to obtain a direct measure. The only acceptable indirect measure should be published data or unpublished data that are verified. The same intervals may be used for published or verified data.

V_{BTREE}, ***Tree basal area***. Basal area of trees (V_{BTREE}) is proportional to aboveground plant biomass of trees and is a dependable indication of forest maturity. In bottomland hardwood forests, for example, basal area and stem density both increase early in succession. Thereafter, tree density decreases, and, as the forest reaches maturity, the rate of increase of basal area diminishes to steady-state conditions (Brinson 1990).

Because basal area of trees can be estimated accurately with angle gauges and prisms, indirect measures do not offer any advantage over direct ones. Therefore, measurements at and above the reference standard should receive a 1.0, while all other measures below that level should be assigned an index value proportional to the reference standard.

Index of function

Species composition of the tree, sapling, shrub, and ground cover strata (V_{COMP}), species composition of seedlings, saplings, and regeneration from clonal shoots of plants in the understory (V_{REGEN}), percent canopy cover (V_{CANOPY}), and the combined variables of tree density (V_{DTREE}) and basal area (V_{BTREE}) are used to assess the Maintain Characteristic Plant Community function. The variables must be scaled to existing reference standards appropriate for the physiographic region of interest and wetland class.

$$\textit{Index of Function} = [(V_{COMP} + V_{REGEN} + V_{CANOPY}) + (V_{DTREE} + V_{BTREE})/2]/4$$

Documentation

MAINTAIN CHARACTERISTIC PLANT COMMUNITY

Definition: Species composition and physical characteristics of living plant biomass. The emphasis is on the dynamics and structure of the plant community as revealed by the dominant species of trees, shrubs, seedlings, saplings, and ground cover, and by the physical characteristics of vegetation.

Effects Onsite: Converts solar radiation and carbon dioxide into complex organic compounds that provide energy to drive food webs. Provides seeds for regeneration. Provides habitat for nesting, resting, refuge, and escape cover for animals. Creates microclimatic conditions that support completion of life histories of plants and animals. Creates roughness that reduces velocity of floodwaters. Provides organic matter for soil development and soil-related nutrient cycling processes. Creates both long- and short-term habitat for resident or migratory animals.

Effects Offsite: Provides a source of propagules to maintain species composition and/or structure of adjacent wetlands and supplies propagules for colonization of nearby degraded systems. Provides food and cover for animals from adjacent ecosystems. Provides corridors (migratory pathways) between habitats, enhances species diversity and ecosystem stability, and provides habitat and food for migratory and resident animals. Supports primary and secondary production in associated aquatic habitats. Contributes leaf litter and coarse woody debris habitat for animals in associated aquatic habitats (Bilby 1981).

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{COMP}: Species composition for tree, sapling, shrub and ground cover strata	Three of the dominant species in each of the four vegetation strata match three of the four dominants in equivalent strata of reference standard.	Published lists of dominant species of each stratum show presence of same species as reference standard.	1.0
	As above, but ground cover does not meet reference standard.		0.75
	As above, but ground cover and saplings don't meet reference standard.		0.5
	As above, but only tree stratum meets reference standard.		0.25
	None of the strata meets reference standard.	Site devoid of vegetation or no species shared with reference standard.	0.0
V_{REGEN}: Seedlings/saplings and/or clonal shoots	Ratio of seedling/sapling species to canopy species is within 75% of the ratio for reference standard.	Published lists or unpublished lists that are verified and show same species composition as reference standard.	1.0
	As above, but between 25% and 75% of the ratio of reference standard.		0.5
	As above, but between 0% and 25% of the ratio of reference standard.		0.1
	Seedlings/saplings and/or clonal shoots are absent or share no species with reference standard sites.	Site devoid of vegetation or no species shared.	0.0
V_{CANOPY}: Canopy cover	Measure of canopy cover is >75% of reference standard.	Remote or other indirect methods not recommended.	1.0
	As above, but between 25% and 75% of reference standard.		0.5
	As above, but between 0% and 25% of reference standard.		0.1
	Canopy cover is absent.		0.0

V_{DTREE}: Tree density	Measured or estimated tree density is between 75% and 125% of reference standard.	Stage of succession similar to reference standard.	1.0
	Tree density is between 25% and 75%, or between 125% and 200%, of reference standard.	Stage of succession departs significantly from reference standard.	0.5
	Tree density is between 0% and 25%, or greater than 200%, of reference standard; restoration possible.	Stage of succession at extreme departure from reference standard; restoration possible.	0.1
	No trees are present; restoration not possible.	Stand cleared; no restoration possible.	0.0
V_{BTREE}: Tree basal area	Basal area or biomass is greater than 75% of reference standard.	Stage of succession similar to reference standard.	1.0
	Basal area or biomass between 25% and 75% of reference standard.	Stage of succession departs significantly from reference standard.	0.5
	Basal area or biomass between 0% and 25% of reference standard; restoration possible.	Stage of succession at extreme departure from reference standard; restoration possible.	0.1
	No trees are present; restoration not possible.	Stand cleared; no restoration possible.	0.0

$$Index\ of\ Function = [(V_{COMP} + V_{REGEN} + V_{CANOPY} + (V_{DTREE} + V_{BTREE})/2]/4$$

Maintain Characteristic Detrital Biomass

Definition

The production, accumulation, and dispersal of dead plant biomass of all sizes. Sources may be onsite or upslope and upgradient. Emphasis is on the amount and distribution of standing and fallen woody debris.

Discussion of function and rationale

This function refers primarily to categories of detritus known as fine woody detritus (wood <10 cm in diameter) and coarse woody debris (wood >10 cm diameter). Fine and coarse woody debris (Harmon et al. 1986) are part of the detritus pools of ecosystems. Woody debris contributes to the functioning of ecosystems by reducing erosion and helping build soils (McFee and Stone 1966). Decomposing detritus also provides wildlife habitat and serves as a store of nutrients and water (Franklin, Shugart, and Harmon 1987;

Harmon et al. 1986; Thorp et al. 1985). Woody debris is a major source of energy, and a major habitat for decomposers and other heterotrophs (Harmon et al. 1986; Seastedt, Reddy, and Cline 1989). Coarse woody debris and debris dams (Smock, Metzler, and Gladden 1989) also play an important role in the dynamics of floodplain-stream ecosystems (Bilby 1981).

Fine woody detritus normally is associated with the forest floor while coarse woody debris has both vertical and horizontal components. Standing dead trees (snags), for example, may account for a large amount of coarse woody debris in forests and provide key habitat for many species (Harmon and Hua 1991). Fallen trees and tree branches that come into contact with the soil surface undergo decomposition at a faster rate than standing trees. It is the decomposition process that ultimately converts wood into material that becomes incorporated into soil and recycles nutrients between living and dead biomass (Harmon et al. 1986).

One way of assessing this function is to evaluate the amount and distribution of woody debris relative to reference standards developed from sites that are mature and are likely to have stable accumulations of detritus. The amount of both fine and coarse woody debris can vary greatly as a result of storms, e.g., Hurricane Hugo's effect on the Congaree Swamp National Monument, a riverine floodplain forest in South Carolina (Putz and Sharitz 1991).

Description of variables

V_{SNAGS}, ***Density of standing dead trees (snags).*** Standing dead trees (snags) are a normal component of floodplain and riparian wetlands dominated by trees. The density of standing dead trees provides information on the suitability of a site as animal habitat and whether or not a site is mature. A forested wetland may also contain more standing dead trees than the reference standard as a result of modifications to its hydrologic regime. For example, a restriction in the flow of a stream caused by the construction of a road crossing would lead to a die-off of less flood-tolerant trees on the affected floodplain. Beaver dams built along a low-gradient reach of a stream can lead to a similar density or biomass of standing dead trees. Because the two sites would probably receive similar variable index scores for this variable, it might be useful to recognize beaver-dominated wetlands as a separate subclass, so that the more temporary and natural influence of beaver can be distinguished from the more permanent drainage constriction caused by road construction. In some cases, the natural beaver-influenced system might be the subclass upon which reference standards are developed. When establishing a reference domain or comparing assessment areas, one should also be aware of alternative explanations for site characteristics. For example, diseases (e.g., Dutch elm disease) can be responsible for high mortality rates of trees in floodplain forests.

The number of standing dead trees at an assessment site should be counted or estimated (categorical data) and compared to its reference standard. If the density is >75 percent of the reference standard, an index score of 1.0 should be assigned. Comparisons that are between 25 and 75 percent of the reference standard should be scored as 0.5, while those falling below 25 percent should be assigned 0.1. If an assessment site has no standing dead trees, a score of 0.0 should be given. There is no suitable indirect measure for this variable at the 1.0 level. However, if leaf-off aerial photography at a suitable scale is available, indirect indices can be obtained for sites that cannot be sampled. A variable score of 0.5 should be given if the aerial photographs show an assessment site has >75 percent of the density of the standing dead trees relative to its reference standard. Values less than 75 percent are scored 0.1, and a score of zero is given when no standing dead trees are visible on aerial photographs.

V_{CWD}, ***Coarse woody debris***. Down and dead trees, branches, etc., on the forest floor represent coarse woody debris (CWD). CWD provides important wildlife habitat and can serve as a refuge for animals during floods. The volume of fallen logs can be measured at an assessment site (indirect measure of biomass) and compared to its reference standard.

If the volume of fallen logs is >75 percent of its reference standard, then a score of 1.0 should be given. Comparisons that place the assessed site at 25 to 75 percent of reference standard should be scored as 0.5, while those from 0 to <25 percent are scored as 0.1. If an assessment site has no coarse woody debris on the soil surface, the variable should be scored 0.0. It would be very difficult to obtain an indirect measure of this variable. The only other suitable way to determine the indicator for this variable would be to examine high-quality aerial photographs taken during the leafless season. Aerial photographs should be used only if they are recent and it is known that the site has not been altered since the photographs were taken. There is no appropriate indirect measure if the site is dominated by evergreen trees. A variable score of 0.5 should be given if the aerial photography shows that an assessment site has >50 percent of the density of fallen logs relative to its reference standard. Values <50 percent are scored as 0.1, and an index score of 0.0 is given when no fallen logs are visible on aerial photographs.

V_{LOGS}, ***Logs in several stages of decomposition***. Decomposing logs contribute nutrients and organic matter to soils. Logs also provide habitat for animals that use them as resting sites, feeding platforms, and as sources of food (Harmon et al. 1986). Mature riparian forests contain logs in various stages of decomposition, indicating steady recruitment of coarse woody debris to a forest floor as a result of tree death. A standard protocol is available for assessing stages of decomposition of coarse woody debris (Harmon et al. 1986), but for purposes of this functional assessment method, it is only necessary to compare the range of conditions found among decomposing logs at the assessment site with information from reference standard sites.

The volume of fallen logs is assessed to estimate the biomass of coarse woody debris (V_{CWD}). These same logs can be assessed to determine their stage of decomposition. For "logs in several stages of decomposition" variable (V_{LOGS}), a direct measure could be used to determine the number of the abundance (e.g., common, rare, absent) of decomposition stages of logs present, based on the following categories:

Class 1: Logs recently fallen and show little decay; bark still present; and leaves and fine twigs are often still present.

Class 2: Logs relatively undecayed but no leaves and fine twigs present; bark starting to fall off; fungal sporocarps (mushrooms) start to appear at this stage.

Class 3: Logs with no bark and only a few branch stubs remaining.

Class 4: Logs with no branches or bark cover; outer parts of the log may be gone leaving some heartwood that is still undergoing decomposition.

Class 5: Logs elliptical in cross section (indicative of advanced decay) and wood often scattered across the soil surface.

If the assessment site has more than 75 percent of the range of log decay classes, a score of 1.0 should be given. If an assessment site has 25 to 50 percent of the log decay classes, 0.5 should be given. If an assessment site contains 0 to 25 percent of the possible decay classes, a score of 0.1 should be given. If the assessment site contains no logs, a score of 0.0 should be given. There is no suitable indirect measure for this variable even if published or unpublished data exist for an assessment site because a site visit would be necessary to verify such information. A direct measure is the only appropriate measurement for this variable.

***V_{FWD}*, Fine woody debris (accumulating in active channels and side channels).** This variable refers to woody components smaller than coarse woody debris and includes both fine wood detritus and leaf litter. Hydrologic interactions between streams and riparian/floodplain areas are dynamic. Water redistributes materials within a floodplain, and woody debris often accumulates on wetland surfaces or in channels that are filled with water when the stream floods. The accumulation of woody debris in piles of various sizes is one of the most obvious signs that a riparian/floodplain zone actively interacts with its associated stream. Piles of woody debris serve to retain dissolved and particulate nutrients, provide habitat for decomposers and organisms that shred leaf litter, and provide temporary habitat for stream vertebrates and invertebrates (Gregory et al. 1991).

This variable is assessed by comparing the abundance of accumulated woody debris in an assessment site with information from its reference standard. When the amount and distribution of accumulated organic matter in the assessment site is approximately similar to the amount found in the reference standard sites, a score of 1.0 should be given. If the amount and distribution of accumulated debris is between 25 and 75 percent of the reference standard, a score of 0.5 should be given. When the assessment site contains little accumulated organic matter (between 0 and <25 percent) relative to the reference standard, it should score 0.1. When there is very little or no accumulated organic matter compared to the reference standard, the variable should score zero. There is no suitable indirect measure for this variable.

Index of function

The abundance of standing (V_{SNAGS}) and downed (V_{CWD}) logs, the decay stages of the logs (V_{LOGS}), and the abundance of piles of accumulated organic matter (V_{FWD}) are variables used to assess the detritus function. All variables must be scaled to existing reference standards appropriate for the physiographic region and the wetland class.

$$\textit{Index of Function} = \{V_{SNAGS} + [(V_{CWD} + V_{LOGS})/2)] + V_{FWD}\}/3$$

The standing dead tree variable is assumed to be as important as the average of the variables for decay stages and abundance of downed logs, and to fine woody debris.

Documentation

MAINTAIN CHARACTERISTIC DETRITAL BIOMASS

Definition: The production, accumulation and dispersal of dead plant biomass of all sizes. Sources may be onsite or upslope and upgradient. Emphasis is on the amount and distribution of standing and fallen woody debris.

Effects Onsite: Provides primary resources for supporting detrital-based food chains, which support the major nutrient-related processes (cycling, export, import) within wetlands. Provides important resting, feeding, hiding, and nesting sites for animals of higher trophic levels. Provides surface roughness that decreases velocity of floodwaters. Retains, detains, and provides opportunities for in situ processing of particulates. Primarily responsible for organic composition of soil.

Effects Offsite: Provides sources of dissolved and particulate organic matter and nutrients for downstream ecosystems. Contributes to reduction in downstream peak discharges and delayed downstream delivery of peak discharges. Contributes to downstream water quality through particulate retention and detention.

Variables	Direct Measure	Indirect Measure	Index of Variable
V_{SNAGS}: Density of standing dead trees	Density >75% of reference standard.	No suitable measure available.	1.0
	Density between 25% and 75% that of reference standard.		0.5
	Density between 0% and 25% of reference standard.		0.1
	No standing dead trees; restoration not possible.		0.0
V_{CWD}: Coarse woody debris (CWD)	Biomass of CWD is >75% and <125% that of reference standard.	Average diameters and lengths of CWD >75% and <125% that of reference standard.	1.0
	Biomass of CWD between 25% and 75% that of reference standard.	Average diameters and lengths of CWD between 25% and 75% that of reference standard.	0.5
	Biomass of CWD between 0% and 25% that of reference standard; restoration possible.	Average diameters and lengths of CWD between 0% and 25% that of reference standard; restoration possible.	0.1
	No CWD present; restoration not possible.	No CWD present; restoration not possible.	0.0
V_{LOGS}: Logs in several stages of decomposition	Greater than 75% of the range of log decay classes relative to reference standard.	No suitable indirect measure	1.0
	Between 25% and 75% of log decay classes relative to reference standard.		0.5
	Logs are only one decay class regardless of average diameter and length.		0.1
	Site contains no logs.		0.0
V_{FWD}: Fine woody debris (accumulating in active channels, side channels, and/or micro-topographic depressions)	Cover of fine woody debris >75% of reference standard.	No suitable indirect measure.	1.0
	Cover of fine woody debris between 25% and 75% of reference standard.		0.5
	Cover of fine woody debris between 0% and 25% of reference standard.		0.1
	No surface woody debris present.		0.0

$$Index\ of\ Function = \{V_{SNAGS} + [(V_{CWD} + V_{LOGS})/2] + V_{FWD}\}/3$$

Maintain Spatial Structure of Habitat

Definition

The capacity of a wetland to support animal populations and guilds by providing heterogeneous habitats.

Discussion of function and rationale

This function is designed to compare the suitability of vegetation structure for sustaining animal populations. Vegetation structure refers to dimensional complexity (cavities, canopy gaps, vertical partitioning of vegetative strata, etc.) and not to species composition. Because structure is an important habitat component for resident and nonresident animals, communities possessing greater structural complexity often are more diverse and species rich. If intensive studies of wildlife and animal communities are needed and justified, the more time-consuming "Habitat Evaluation Procedure" should be used (U.S. Fish and Wildlife Service 1980).

Vegetation of mature, intact riverine ecosystems reflects the constraints imposed by environmental parameters (climate, hydrologic regime, edaphic factors, geomorphology, etc.) and the competitive interactions of its plants. Wetland vegetation patterns of altered riverine systems are affected by current and past disturbances, in addition to the constraints previously listed.

Most large river systems and many smaller ones in the continental United States have been dramatically altered by dams, levees, diversions, and abstractions (Stanford and Ward 1979). Therefore, present vegetation patterns in riverine wetlands often reflect past and ongoing anthropogenic alterations in hydrogeomorphic conditions.

Plant communities provide complex, three-dimensional structure in riparian zones for both vertebrates and invertebrates. Food, shelter (cover), nesting, breeding, and foraging depend, in part, on the complexity and composition of this vegetation. Forested wetlands, particularly mature systems with a full complement of age classes, are vertically stratified into canopy (overstory tree species), subcanopy (understory trees and younger overstory species), shrub, and ground cover (both herbaceous and woody vegetation layers). As vertical complexity of forests increases due to the number of strata, both the abundance of individuals and species richness increases.

Habitat patchiness is another factor that controls animal species richness and diversity. The types and distribution of ecotones (sharp boundaries in vegetation types) and canopy gaps affect ecosystem processes and species composition. The scale at which patchiness is evaluated determines the reliability and usefulness of the measurements.

The goal of assessing the habitat structure function is to evaluate the structural and spatial complexity of a wetland plant community, particularly those components that affect animal populations. This function must be examined in the context of reference standards for a hydrogeomorphic subclass (i.e., one must be cognizant that reference standards may vary regionally, among rivers of the same region, and between different reaches of the same river).

Description of variables

V_{SNAGS}, Density of standing dead trees (snags). Standing dead trees are important in contributing to habitat structure. Mature forests (in which tree senescence is common) and forests subjected to periodic disturbances on the order of decades or longer (outbreaks of insect infestations and disease, hurricanes, etc.) usually possess standing dead trees (snags). The importance of snags to woodpecker foraging is well established (they feed on insects in decomposing snags). In addition, limbs of large snags provide resting, perching, feeding, and nesting sites for large birds, particularly raptors (eagles, osprey, etc.). Other avian predators (kingfishers, cormorants, owls, etc.) use snags for resting, feeding, searching for prey, and drying-out (cormorants). Neotropical songbirds, waterfowl, and woodpeckers nest within snag cavities. Mammals (bears, squirrels, mice, etc.) and reptiles (snakes, lizards, etc.) use snags for feeding, nesting, and hunting. Amphibians (frogs, salamanders, etc.) use coarse woody debris (CWD), and thus are ultimately dependent on a supply of CWD from snags. Snags are an extremely important habitat for animal populations that exploit forested wetlands.

Density determinations should focus on the larger size classes of snags (with respect to reference standards), because large snags provide the widest range of potential habitats for use by animals. While an analysis of canopy species composition is not necessary to determine the condition of this variable (V_{SNAGS}), such an analysis could be beneficial in estimating the time required for an assessment site to approach a project target via succession.

The density of snags is most appropriately determined through direct measurements. However, if measuring is not possible, aerial photographs may be used if dead and living trees can be discriminated and counted. Discrimination may be possible in some evergreen coniferous forests. Great caution must be exercised when using remotely sensed data in deciduous forests because it is difficult during leafless periods to distinguish living from dead trees; during the growing season, leaves of neighboring trees may obscure observation of snags.

If the frequency of snags is >75 percent of its reference standard, an index variable score of 1.0 should be given. If snag density has been altered through timber management, or some other disturbance that lowers snag density to between 75 and 25 percent, a variable index score of 0.5 should be given. If snag density is between 25 and 0 percent or there is potential to create snags, a score of 0.1 is given. If there are no snags present, and there is no potential for creating snags, a score of zero should be given.

V_{MATUR}, ***Abundance of very mature trees.*** Standing mature or dying trees provide nesting habitat for a variety of animal species, including invertebrates, birds, reptiles, amphibians, and mammals. The direct measure of habitat, that of counting potential cavities, is difficult because cavities are often obscured from sight by an observer on the ground. Consequently, accuracy is greatly sacrificed in rapid assessments (Tom Roberts 1995, personal communication). Other measures or surrogates for cavities, such as determining the density or species richness of cavity-nesting birds, are too time consuming and logistically limiting.

Reference wetlands provide data upon which to establish the tree size considered as very mature, and thus appropriate, habitat for cavity-nesting animals. Very mature trees may be determined by recording densities of trees greater than some predefined diameter appropriate to the forest community being assessed. Index scores may be determined as in V_{SNAGS} above.

V_{STRATA}, ***Number and attributes of vertical strata of vegetation.*** Mature forested wetlands are usually vertically stratified in temperate North America. Riverine forests generally possess more than three strata. Because forest organisms exhibit a remarkable fidelity to a particular stratum, differences in structure between sites likely represent differences in animal composition between sites as well. In fact, more spatially stratified communities often contain more species.

Vertical stratification must be measured directly and compared with the reference standard when assessing a site. No indirect measure is available. The number of strata, density, or cover of plants in each stratum, or some composite index, should be developed that is appropriate to the reference domain. A condition >75 percent of reference standards should receive a variable index score of 1.0. Conditions between 75 and 25 percent of the reference standard should score 0.5. Assessment sites that possess between 0 and 25 percent of the reference standard (with potential for restoration) should be scored 0.1. Sites that have no potential to recover vertical stratification similar to that of the reference standard should score a zero.

V_{PATCH}, ***Vegetation patchiness.*** Heterogeneity in distribution and abundance (patchiness) of organisms is inherent at all scales in every natural ecosystem. Any measure of ecosystem attributes must consider the appropriate scale and sample size in which to measure those attributes in order to understand ecosystem processes (competition, trophic interactions, energy flow, habitat structure). Wetlands are no exception. Habitat heterogeneity occurs across different spatial scales for different plant life forms (canopy, shrub, herbaceous, etc.) and across different hydrogeomorphic classes. Patchiness of vegetation affects the types and abundances of trophic interactions, energy flow, and competition among animals. These processes in turn affect animal populations. Plants are rarely uniformly distributed in wetlands, and observed patterns can often be quite complex, ranging from clonal species that are clumped to species that are not very abundant and appear to occur randomly. The level of this variable should be evaluated by detailed sampling and analysis with comparison to the reference standard.

The scale at which patchiness is measured and evaluated determines the reliability and usefulness of measurements. For example, shrubs and trees may not be uniformly distributed across a forested wetland landscape. A closed canopy may give way to a shrub/scrub thicket near a tributary. Each habitat type supports a different assemblage of animal species, and so the combined species richness of several habitats is greater than the richness of any area evaluated separately. Hence, areas with a more diverse array of habitat types would support more species than those with less diverse internal patchiness. Using the appropriate scale and reference domain is critical to determining the variable condition of an assessment site. Transects laid perpendicular to the length of the stream channel can be used to determine discontinuities in vegetation and their frequency per unit distance. Indirect measures (for example, examining aerial photos) can be used, but methods depend upon the scale at which patchiness is to be assessed and the types of organisms that rely on parameters associated with the habitat patchiness. For example, insects, small mammals, and large wide-ranging mammals each rely on different scales of patchiness.

Patchiness between 75 and 125 percent of its reference standard should receive a variable index score of 1.0. Patchiness between 75 and 25 percent or > 125 percent of its reference standard should score 0.5. Assessment sites that are between 0 and 25 percent of this reference standard for patchiness (and in which patchiness can be restored) should be scored 0.1. Sites that have no potential for restoring patchiness to the reference standard should receive a zero score.

V_{GAPS}, ***Canopy gaps.*** Death of canopy trees is a normal process that has important implications for the dynamics of ecosystems. Openings in the canopy allow more light to reach the ground, and consequently they play an important role in reproduction of plants and creating patchiness in the understory. Canopy gaps create microclimate variation within forests and serve as focal points for foraging animal feeding.

The nature of canopy gaps is distinct from the variable of vegetation patchiness. Canopy gaps are created by windfall, while patchiness of vegetation may occur in other strata. Canopy gaps are often indicative of forest maturity, particularly in assessing unaltered sites. Mature sites are normally used to represent the reference standard because they generally support the highest biodiversity and overall functioning across the suite of functions. However, canopy gaps may reflect anthropogenic disturbances and in such cases should be used with caution.

Aerial photographs may be interpreted to obtain an indirect measure during period of leaf-out. Direct measures may be made by determining percent of linear transects intercepting gaps or area of gaps per unit area of landscape. Gaps can also be expressed as density per unit area.

Gap area or density that is between 75 and 125 percent of reference standards should receive a variable index score of 1.0. Conditions between 75 and 25 percent or > 125 percent of the reference standard should score 0.5. Assessment sites that are between 0 and 25 percent of the reference standard (with potential for recovery given sufficient time) should be scored 0.1. Immature forests normally lack canopy gaps but should develop them as they mature; such sites should be scored 0.1. Sites than have no potential for recovery to the reference standard (development of gaps not possible) should receive a zero score.

Index of function

The variables density of standing dead trees (V_{SNAGS}), abundance of mature trees (V_{MATUR}), number and attributes of vertical strata (V_{STRATA}), vegetation patchiness (V_{PATCH}), and canopy gaps (V_{GAPS}) are used to assess the function Maintain Spatial Structure of Habitat. Each indicator, whether determined via direct or indirect measure, must be scaled to a suite of reference wetlands and conditions appropriate for the physiographic region and wetland subclass.

$$Index\ of\ Function = (V_{SNAGS} + V_{MATUR} + V_{STRATA} + V_{PATCH} + V_{GAPS})/5$$

Each variable is assumed to be of equal importance.

Documentation

MAINTAIN SPATIAL STRUCTURE OF HABITAT

Definition: The capacity of a wetland to support animal populations and guilds by providing heterogeneous habitats.

Effects Onsite: Provides potential feeding, resting, and nesting sites for vertebrates and invertebrates. Regulates and moderates fluctuations in temperature. Provides habitat heterogeneity to support a diverse assemblage of organisms. Affects all ecosystem processes.

Effects Offsite: Provides habitat heterogeneity to landscape, provides habitat for wide-ranging and migratory animals, provides a corridor for gene flow between separated populations, and allows progeny to exploit new areas.

Variables	Direct Measure	Indirect Measure	Index of Variable
V_{SNAGS}: Density of standing dead trees	Density >75% of reference standard.	In selected forest types, aerial photos may be used to estimate density.	1.0
	Density between 25% and 75% of reference standard.		0.5
	Density between 0% and 25% of reference standard.		0.1
	No standing dead trees.		0.0
V_{MATUR}: Abundance of very mature trees	Density of very mature trees >75% of reference standard.	No suitable measures available.	1.0
	Density of very mature trees between 25% and 75% of reference standard.		0.5
	Density of very mature trees between 0% and 25% of reference standard; restoration possible.		0.1
	No very mature trees; no potential for restoration.		0.0
V_{STRATA}: Number and attributes of vertical strata of vegetation	1. Number of vertical strata, or 2. Density or cover of plants in each stratum, or 3. Some composite index of above is >75% of reference standard.	Complexity of canopy (number of strata) shown on recent aerial photographs taken in leaf season, with field calibration, similar to reference standard.	1.0
	As above, but between 25% and 75% of reference standard.	As above, but less than reference standard.	0.5
	As above, but between 0% and 25% of reference standard.	No canopy; restoration possible.	0.1
	Vertical strata missing.	No canopy; restoration not possible.	0.0
V_{PATCH}: Vegetation patchiness	Appropriate measure of patchiness >75% and <125% of reference standard.	Texture of canopy shown on recent aerial photographs taken in leaf season, field calibrated, similar to reference standard.	1.0
	As above, but between 25% and 75% or >125% of reference standard.	As above, but less than reference standard.	0.5
	As above, but between 0% and 25% of reference standard.		0.1

V_{PATCH}: (Concluded)	No canopy present.	Recent aerial photographs show no tree canopy.	0.0
V_{GAPS}: Gaps in forest	Number, distribution, or size frequency of gaps in the forest canopy 75% to 125% of reference standard.	Recent aerial photographs taken during leaf-out season show gaps in the tree canopy similar in number, size, and abundance to reference standard.	1.0
	As above, but between 25% and 75% or >125% of reference standard.	As above, but less than reference standard.	0.5
	As above, but between 0% and 25% of reference standard.		0.1
	No canopy gaps present.	Methods above indicate no gaps in the tree canopy.	0.0

$$\text{Index of Function} = (V_{SNAGS} + V_{MATUR} + V_{STRATA} + V_{PATCH} + V_{GAPS})/5$$

Maintain Interspersion and Connectivity

Definition

The capacity of a wetland to permit aquatic organisms to enter and leave the wetland via permanent or ephemeral surface channels, overbank flow, or unconfined hyporheic gravel aquifers. The capacity of wetland to permit access of terrestrial or aerial organisms to contiguous areas of food and cover.

Discussion of function and rationale

Riverine floodplains and the wetlands associated with them are used extensively by both terrestrial and aquatic animals to complete portions of their life histories (i.e., spawning by fish, nesting by waterfowl) (Minshall, Jensen, and Platts 1989; Welcomme 1979, Wharton et al. 1982). Adequate habitat corridors are required for connecting wetlands to other ecosystems. Aquatic vertebrates enter floodplain wetlands during flooding, most often via small connections from side or main channels. Natural or man-made levees may restrict surface connections to wetlands during low flood years. In contrast, large areas of a river corridor may be flooded during large events, permitting unrestricted access across a floodplain surface.

Riverine wetlands in floodplains containing coarse gravel sediments are often directly connected via subsurface paleo-channels to the main flow of the river (Stanford and Ward 1993). This permits a rapid exchange between channel surface water and subsurface flow. Such hyporheic waters, particularly those in gravel bed rivers, permit the development of complex, underground food webs that sustain exchanges of nutrients, microbes, and aquatic insects between a channel and the wetland (Stanford and Ward 1988, 1992).

Wetlands of riverine floodplains often support a heterogeneous mosaic of habitat types at a variety of temporal and spatial scales. For example, depressions on a floodplain surface may hold water for long periods between floods, thus supporting aquatic organisms and more flood-intolerant plants than nearby, less wet sites. Likewise, channels connecting a floodplain to the main river are important conduits of seed dispersal to and from wetlands.

Wetlands also provide water and other life requirements for motile species that primarily exploit upland habitats. In addition, all vegetational strata in wetlands, from herbaceous layer to tree canopy, provide wildlife corridors (connections) between different wetland types, between uplands and wetlands, and between uplands (Sedell et al. 1990). Such connections between habitats help maintain higher animal and plant diversity across the landscape than would be the case if habitats were more isolated from one another.

Description of variables

V_{FREQ}, ***Frequency of overbank flow.*** The frequency of overbank flow is a critical component of the character of riverine wetland. Overbank flow is often necessary in affording access to riverine wetlands by anadromous or adfluvial fishes that use floodplain habitats to complete portions of their life histories, such as spawning and rearing (Ward 1989). The temporal periodicity and magnitude of flooding may have direct bearing on strengths of year classes among vertebrates. Likewise, overbank flow and connectivity between the main channels and floodplain wetlands facilitate the dispersal of plant seeds and other propagules. Thus, flooding and connectivity are critical components of site-specific structure and function.

Overbank flow is best quantified by hydrographic data which can be used as a direct measure of this variable. Such data may be obtained from either federal or state agencies that maintain hydrogeographic databases. The reference standard is the frequency of overbank flow found in wetlands used for reference standards. If the frequency of overbank flow of assessment site is similar to the reference standard, an index score of 1.0 is given. If frequencies are greater than or less than the reference standard, lower scores are assigned. If there is no flooding by overbank flow, the variable should receive a zero score.

V_{DURAT}, ***Duration of overbank flow.*** The duration of overbank flow is determined by both discharge upriver and the volume of water that is dissipated across and temporarily stored on adjacent floodplains during floods. Thus, the duration of overbank flow is affected by the size of the floodplain and the hydraulic connectivity between the main channel and associated floodplain wetlands (Stanford and Ward 1993).

Duration of flooding is important in permitting organisms sufficient time to access floodplain wetlands for spawning and feeding, and in allowing some species to complete important life-history developmental stages. Longer periods of flooding may also aid in the dispersal of some plants. However, it should be kept in mind that what benefits one set of organisms may be detrimental to others. Therefore, an assessment site must be compared with the appropriate reference standard to determine its index score. If the duration of overbank flow at the assessment site has a temporal magnitude of between 75 and 125 percent that of its reference standard, an index score of 1.0 should be given. If overbank flow occurs within a temporal magnitude between 25 and 75 percent or >125 percent compared to the reference standard, an index score of 0.5 should be given. If the assessment area rarely floods or flooding occurs for a very short time period (between 0 and 25 percent), 0.1 should be recorded. If no flooding occurs, a zero should be scored for the variable.

V_{MICRO}, ***Microtopographic complexity.*** Microtopographic complexity is an important factor contributing to the interspersion of habitat types and connections between river and floodplain wetlands. Elevated structures (for example, hummocks) and low areas (channels and small depressions) direct the flow of water through wetlands, and affect the direction and duration of flows. Wetlands with a mosaic of interspersed habitat types provide conditions suitable for a higher diversity of plant and animal species than do wetlands with uniform topography.

A direct measure of microtopographic complexity is acquired by performing a survey of microtopography (using an auto-level, laser-total survey, etc.) within a well-designed suite of transects intersecting the wetland. The indirect measure is a visual assessment of the wetland surface. The reference standard for this variable must be based on data obtained from reference standard sites. If an assessment site contains between 75 and 125 percent of the frequency and depth of microtopographic depressions in comparison to its reference standard, an index score of 1.0 should be given. Lower scores are given (0.5 or 0.1) as microtopographic depressions decrease in frequency and magnitude. If an assessment site has no microtopographic depressions or its natural substrate has been replaced by an artificial surface, a score of zero should be given.

$V_{SURFCON}$, ***Surface hydraulic connections.*** Multiple hydraulic connections between a river and wetlands on its floodplain strongly indicate a high heterogeneity of habitats (and hence, relatively high species diversity), interspersion among habitat types, and potential for complex trophic interactions (Foreman and Godron 1981, Gregory et al. 1991). Reference wetlands provide examples, such as lateral or secondary channels and gaps in levees. If the frequency of surface hydraulic connections between the wetland and the river channel is >75 percent that of its reference standard, an index score of 1.0 should be given. Lower scores are given (0.5 or 0.1) as the number of connections decrease. If an assessment site has no hydraulic connectivity to the main channel or side channels, a score of zero should be given.

V_{SUBCON}, ***Subsurface hydraulic connections.*** High-energy streams and floodplains with coarse gravels usually have subsurface hydraulic connections that provide a conduit for small aquatic organisms to move back and forth between habitats without leaving their aquatic environment. Aquatic insects are particularly well adapted to exploiting this connection. Reference wetlands provide examples (such as springs, seeps, and upwellings) that illustrate both lateral and longitudinal connections through hyporheic flow. Local conditions need to be examined in order to find indicators to quantify this variable, and to scale this variable according the conditions found at reference standard sites. This variable may not be applicable for floodplains and streams dominated by silt and clay alluvium, a condition which minimizes the availability of effective connections.

V_{CONTIG}, ***Contiguous vegetation cover and/or corridors between wetland and upland, between channels, and between upstream-downstream areas.*** Continuity of vegetation, connectivity of specific vegetation types, the presence and scope of corridors between upland/wetland habitats, and corridors among wetlands all have direct bearing on the movement and behavior of animals that use wetlands (Pautou and Décamps 1985). Assessment of this variable is region-specific, and must be placed in the context of the animal species that are known to utilize such connections. For example, both white-tail deer and passerines are known to use vegetative corridors for cover in bottomland hardwoods, but the cover required by the two groups differs. If an assessment site is equivalent to its reference standard, a score of 1.0 should given. Lower scores are given (0.5 or 0.1) as the density of vegetation mosaics and the connectivity via vegetation or channel corridors decrease. If an assessment site has no connectivity to upland vegetation or riverine channels, a score of zero should be given for the variable.

While the foregoing provides rough guidelines, the contiguity variable will have to be scaled both to the organisms of interest and the size of the stream-floodplain complex being assessed.

Index of function

The variables—frequency of overbank flow (V_{FREQ}), duration of overbank flow (V_{DURAT}), microtopographic complexity (V_{MICRO}), surface hydraulic connections ($V_{SURFCON}$), subsurface hydraulic connections (V_{SUBCON}), and contiguous vegetation cover and/or corridors between wetland and upland, between channels, and between upstream-downstream areas (V_{CONTIG})—are used to assess the function in maintaining habitat interspersion and connectivity. Each indicator, whether determined via direct or indirect measures, must be scaled to a suite of reference wetlands and conditions appropriate for the physiographic region of the wetland's functional class.

$$Index\ of\ Function = (V_{FREQ} + V_{DURAT} + V_{MICRO} + V_{SURFCON} + V_{SUBCON} + V_{CONTIG})/6$$

Documentation

MAINTAIN HABITAT INTERSPERSION AND CONNECTIVITY

Definition: The capacity of a wetland to permit aquatic organisms to enter and leave the wetland via permanent or ephemeral surface channels, overbank flow, or unconfined hyporheic gravel aquifers. The capacity of a wetland to permit access of terrestrial or aerial organisms to contiguous areas of food and cover.

Effects Onsite: Provides habitat diversity. Contributes to secondary production and complex trophic interactions. Provides access to and from wetland for reproduction, feeding, rearing, and cover. Contributes to completion of life cycles and dispersal between habitats.

Effects Offsite: Provides corridors for wide-ranging or migratory species. Provides refugia for plants and animals. Provides conduits for dispersal of plants and animals to other areas.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{FREQ}: Frequency of overbank flow	Gauge data (1.5) yr return interval similar to reference standard. (Interval in parentheses must be adjusted to the reference standard.)	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0
	Gauge data (>2 or <1) yr return interval.	As above, but somewhat greater or less than reference standard.	0.5
	Gauge data show extreme departure from reference standard.	Above indicators absent but related indicators suggest overbank flow may occur.	0.1
	Gauge data indicate no flooding from overbank flow.	Indicators absent and/or alteration has eliminated variable.	0.0
V_{DURAT}: Duration of overbank flow	Gauge data (x-y) yr show duration between 75% and 125% of reference standard. (Duration in parentheses must be adjusted to the reference standard.)	Duration of connection related indicators only, and similar to reference standard.	1.0

V_{DURAT}: (Concluded)	As above, but between 25% and 75% or >125% of reference standard.	Any indicators, i.e., aerial photos showing continuity of duration, flooding tolerance of tree species, etc., showing continuity of flooding as less than reference standard.	0.5
	As above, but between 0% and 25% of reference standard.	Any indicators showing greatly reduced duration relative to reference standard.	0.1
	Gauge data indicate no overbank flow.	Flooding is absent.	0.0
V_{MICRO}: Microtopographic complexity	Microtopographic complexity (MC) measured (surveyed) at site shows MC between 75% and 125% of reference standard.	Visual estimate indicates that microtopographic complexity (MC) of site is between 75% and 125% of reference standard.	1.0
	As above, but MC of site is between 25% and 75% that of reference standard.	Visual assessment confirms MC is present, but somewhat less than reference standard.	0.5
	Measured MC between 0% and 25% of reference standard; restoration possible.	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1
V_{MICRO}: (Concluded)	No MC at assessed site or natural substrate replaced by artificial surface; restoration not possible.	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0
$V_{SURFCON}$: Surface hydraulic connections	Use of data from runoff collectors as a continuous variable from reference standard (1.0) to absent (0.0).	Number of surface connections 75% to 125% of reference standard.	1.0
		Surface connections 25% to 75% of reference standard.	0.5
		As above, but 0% to 25% of reference standard.	0.1
		No surface connections due to obstructions or alterations.	0.0
V_{SUBCON}: Subsurface hydraulic connections	Direct measures not practical. Tracer and dye methods are required.	Seeps, springs, upwellings similar to reference standard.	1.0
		Excessive fine sediment supply sufficient to block subsurface connections.	0.5
		Stream channel and floodplain highly altered with minimal connections.	0.1

V_{SUBCON}: (Concluded)		No possible subsurface connections exist because of alterations.	0.0
V_{CONTIG}: Contiguous vegetation cover	Continuity among vegetation connections between channels, uplands, and upstream-downstream wetland areas >75% of reference standard.	Recent aerial photographs taken during leaf season show abundant vegetation and vegetated corridors connecting mosaics of habitat types similar to reference standard.	1.0
	As above, but continuity between 25% and 75% of reference standard.	Recent aerial photographs taken during leaf season show lower abundance of vegetative connections than reference standard.	0.5
	As above, but continuity between 0% and 25% of reference standard.	Lack of continuous vegetation connections with potential for recovery.	0.1
	Assessment site fragmented and isolated from channels and adjacent uplands and upstream-downstream wetland areas.	Lack of continuous vegetation connections with no potential for recovery.	0.0

$$Index\ of\ Function = (V_{FREQ} + V_{DURAT} + V_{MICRO} + V_{SURFCON} + V_{SUBCON} + V_{CONTIG})/6$$

Maintain Distribution and Abundance of Invertebrates

Definition

The capacity of a wetland to maintain characteristic density and spatial distribution of invertebrates (aquatic, semi-aquatic, and terrestrial).

Discussion of function and rationale

Invertebrate fauna (insects, nematodes, molluscs, etc.) is extremely rich in species and modes of existence in most wetlands. Invertebrates exploit almost every microhabitat available in wetlands. Because invertebrates are so pervasive and partition habitats so finely, they are excellent indicators of ecosystem function. In fact, without invertebrates, wetland ecosystems would fail to function.

Coarse particulate organic matter (CPOM) enters a riverine-wetland ecosystem as allochthonous material from its riparian overstory or from upstream locations. CPOM is generally retained either in the stream or on the riparian floodplain surface where it is used and/or processed through a multitude of consumer pathways. A significant portion of these pathways is mediated by invertebrates that shred leaf litter and burrow into woody material. Emergent and submersed macrophytes also contribute organic matter. Aquatic macrophytes are frequently grazed by invertebrates, or may enter the detrital pool where microbial activity and detritivory by both terrestrial and aquatic invertebrates play important roles in decomposition processes.

Riverine wetlands are often subject to alternating conditions between wet and dry (terrestrial and aquatic) environments. Meander scrolls, for example, may be wet or flooded for extended time periods (e.g., several months) during annual or more frequent inundation intervals (depending on local climatic and hydrologic regimes), but lose surface moisture as dryer conditions return. When surficial standing water is absent, terrestrial invertebrates are important to soil development. These include worms, snails, and small arthropods (e.g., mites, millipedes, centipedes, insects). These organisms are important processors of organic material that add significantly to organic soil development. In breaking down organic matter, these organisms enable soil microbes to transform nutrients from unavailable to available forms. They are also import sources of animal material to higher level consumers (e.g., amphibians, reptiles, birds, and mammals).

Description of variables

V_{SINVT}, Distribution and abundance of invertebrates in soil. Species composition and abundance of soil invertebrates are important determinants of soil condition and confirm that decomposition is occurring. Although identification to the species level is often difficult, familiarity with dominant taxa is fairly easily grasped. Measurements of invertebrate density and species richness must be compared with a reference standard. A direct measure of invertebrate species richness and abundance at an assessment site is best obtained by any of several standard sampling techniques. Rapid assessment is possible in the field by people familiar with dominant invertebrate taxa. Similarity can be determined by comparing density, species richness, or some index of similarity (see ecology textbooks for a discussion of such measures). Invertebrate species using wetlands may be aquatic, semi-aquatic, or terrestrial. Many immature stages of aquatic forms exploit terrestrial or aerial environments as adults; species listed must be scrutinized for aquatic and semi-aquatic life forms (Merritt and Cummins 1995).

If soil invertebrate density and taxa richness (or similarity) is >75 percent of the reference standard, an index value of 1.0 should be given. If an assessment site condition is between 75 and 25 percent of the reference standard, an index value of 0.5 should be recorded. If an assessment site condition is 0 to 25 percent of its reference standard, an index value of 0.1 should be assigned. If there is no evidence of invertebrates in the soil, a value of zero should be given.

Indirect measures may also be used to compare similarities in invertebrate communities between assessment wetlands and reference sites. Indirect indicators include measures of the presence and activity of soil invertebrates, insects, or some other invertebrate category that would reasonably be expected to indicate wetland functions. The type of indirect measurements and the categories to be measured should be those that can be reliably used to compare assessment sites to its reference standard. For a level of invertebrate activity and density at an assessment site that is similar to its reference standard should be given an index score of 1.0. If these indirect measures are reduced in frequency from that of its reference standard, a score of 0.5 is given. If there is no evidence of invertebrate activity in the soil, but there is potential for recovery to reference standard levels, a score of 0.1 should be given. If there is no evidence of soil invertebrates and no potential for recovery, a score of zero should be given.

V_{LINVT}, Distribution and abundance of invertebrates in leaf litter and coarse woody debris. Invertebrates are an essential part of the decomposition of leaf litter and coarse woody debris (CWD) on the forest floor. Organic material in wetland ecosystems is processed through the detrital or grazing food webs. Invertebrates, both terrestrial and aquatic, play important roles in the processing of organic matter, particularly leaf litter (Benfield, Jones, and Patterson 1977; Benke and Meyer 1988; Benke et al. 1984, 1992). By shredding leaves and burrowing into woody material, invertebrates (and soil microbes associated with this process) break down cellulose and lignin of coarse material; this activity is essential to soil development in wetlands. Insects, crustaceans, and oligochaetes are important detritivores in rivers and riverine wetlands, and indicate efficient organic matter processing (Hauer, Poff, and Firth 1986; Reice 1977). Determining invertebrate activity in coarse woody debris is best determined measured directly. Similarity can be determined by comparing density, species richness, or some index of similarity (see any ecology text for a discussion of such measures) at an assessment site with its reference standard.

For direct measures, a variable index score of 1.0 is assigned to assessment sites that show >75 percent similarity to their reference standard. Similarity can be determined by comparing density, species richness, or some index of similarity (see any ecology text for a discussion of such measures). A variable condition in which between 25 and 75 percent of the reference standard is met should score 0.5. Assessment sites that show between 0 and 25 percent of their reference standard should be scored 0.1. Assessment sites devoid of invertebrates associated with the breakdown of leaf litter and coarse woody debris should receive a zero.

Indirect measures of this variable can be made by looking for evidence of invertebrate activity (leaf skeletonization, galleries in logs, etc.). If a site is similar to its reference standard, an index score of 1.0 should be given. An assessment that shows a close similarity between the assessment site and the reference standard should score a 0.5. A comparison that shows a large dissimilarity between the two, but with potential for recovery of the variable at the assessed site, should receive a 0.1 variable index score. Assessment sites devoid of litter invertebrates with no potential for their restoration should receive a zero.

V_{AQINVT}, ***Distribution and abundance of invertebrates in aquatic habitats (e.g., microdepressions, seeps, side channels).*** Aquatic invertebrates are exceptionally diverse taxonomically and often very abundant. Benthic macroinvertebrates may reach densities of thousands of individuals per square meter. During flooding conditions, ephemeral channels and permanent wetlands exchange organic materials with their main channel and are an integral part of upstream-downstream processes that characterize the lotic environment. Habitat diversity in floodplain wetlands is very high; likewise, species richness of aquatic invertebrates is high and density can vary considerably between habitats. Direct measures of aquatic invertebrates should be made using standard sampling techniques. Rapid assessment procedures for aquatic invertebrate sampling, identification, and enumeration are fairly well established, but these methods require specialized training and expertise. All sampling must be done at a time of year that will allow useful comparison with sampling done on reference standard sites.

For direct measures, a variable index score of 1.0 is assigned to assessment sites that show >75 percent similarity to their reference standard. Similarity can be determined by comparing density, species richness, or some index of similarity (see any ecology text for a discussion of such measures). A variable condition in which between 25 and 75 percent of the reference standard for a site is met should score 0.5. Assessment sites that show 0 to 25 percent similarity to their reference standard should be scored 0.1. Assessment sites devoid of aquatic invertebrates should receive a zero.

Indirect measurements of the presence and activity of aquatic invertebrates may be based upon visual estimates of suitable aquatic habitats and the presence of aquatic invertebrate activity (for example, exudates, egg cases, and shell fragments). Not much work has been done to quantify the relationship between such indirect indicators and population estimates, so care must be taken. However, any indirect measures chosen should be suitable for comparing sites in a given reference domain. Index scores should be determined as above.

Index of function

The variables species richness and density (or some similarity index) of invertebrates in soil (V_{SINVT}), species richness and density (or similarity measure) of invertebrates in leaf litter and coarse woody debris (V_{LINVT}), and species richness and density (or a similarity measure) of invertebrates in aquatic habitats (e.g., microdepressions, seeps, and side channels) (V_{AQINVT}) are used to assess the function Maintaining Distribution and Abundance of Invertebrates. Each indicator, whether determined by direct or indirect measures, must be scaled to a suite of reference wetlands and conditions appropriate for the physiographic region and wetland class.

$$Index\ of\ Function = (V_{SINVT} + V_{LINVT} + V_{AQINVT})/3$$

Each variable is assumed to be of equal importance in contributing to this function.

Documentation

MAINTAIN DISTRIBUTION AND ABUNDANCE OF INVERTEBRATES

Definition: The capacity of a wetland to maintain characteristic density and spatial distribution of invertebrates (aquatic, semi-aquatic, and terrestrial).

Effects Onsite: Provides food (energy) to predators, aerates soil and coarse woody debris by building tunnels, breaks down (decomposes) coarse woody debris, increases availability of organic matter for nutrient cycling microbes, and disperses seeds within site.

Effects Offsite: Provides food (energy) for wide-ranging carnivores/insectivores, etc. Transports seeds and propagules for germination elsewhere.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{SINVT}: Distribution and abundance of invertebrates in soil	Similarity index for species composition and abundance ≥75% of reference standard.	Tunnels, shells, casts, holes, etc., in soil similar to reference standard (indirect measures may be developed that can be quantified).	1.0
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	As above, but much less than reference standard.	0.5
	Similarity index for species composition and abundance 0% to 25% of reference standard.	No evidence of items above, but with potential for habitat recovery.	0.1
	No soil invertebrates or evidence of soil invertebrates found.	No evidence of items above and no potential for recovery of habitat.	0.0
V_{LINVT}: Distribution and abundance of invertebrates in leaf litter and in coarse woody debris	Similarity index for species composition and abundance ≥75% of reference standard.	Visual assessment of galleries in logs and twigs, tunnels in wood, shells, casts, trails, holes, etc., similar to reference standard (measures may be developed that can be quantified).	1.0

V_{LINVT}: (Concluded)	Similarity index for species composition and abundance between 25% and 75% of reference standard.	As above, but much less than reference standard.	0.5
	Similarity index for species composition and abundance 0% to 25% of reference standard.	Absence of above conditions, but with potential for habitat recovery.	0.1
	No invertebrates or evidence of invertebrates found in leaf litter or coarse woody debris.	Absence of above conditions but no potential for habitat recovery.	0.0
V_{AQINVT}: Distribution and abundance of invertebrates in aquatic habitats (microdepressions, side channels, seeps)	Similarity index for species composition and abundance ≥75% of reference standard or regional indicator/keystone species.	Presence of suitable aquatic habitats (microdepressions, seeps, etc.) and evidence of shell fragments, exudate, etc., similar to reference standard. Measures may be developed that can be quantified.	1.0
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	As above, but indicators much less than reference standard.	0.5
	Similarity index for species composition and abundance 0% to 25% of reference standard.	No evidence of items above, but with potential for habitat recovery.	0.1
	No invertebrates or evidence of invertebrates found in aquatic habitats.	No evidence of suitable aquatic habitats and no potential for habitat recovery.	0.0

$$Index\ of\ Function = (V_{SINVT} + V_{LINVT} + V_{AQINVT})/3$$

Maintain Distribution and Abundance of Vertebrates

Definition

The capacity of a wetland to maintain characteristic density and spatial distribution of vertebrates (aquatic, semi-aquatic, and terrestrial) that use wetlands for food, cover, rest, and reproduction.

Discussion of function and rationale

Riverine wetlands depend upon physical, chemical, and biological connections to their river channels for a number of processes. These processes support resident, seasonal, and migratory vertebrate species (Blake and Hoppes 1986; Décamps, Joachim, and Lauga 1987). Vertebrate distribution and abundance in any given river and wetland system is not static, but rather is highly dynamic and can change rapidly in both space and time (Matthews 1988). For example, several species of fishes use wetlands as spawning and rearing areas; however, fish are limited in their access to wetlands due to the hydrographic regime of the river and the temporal sequence of flooding events. Thus, maintenance of a particular fish species in a drainage basin may depend on a suitable frequency of flooding and duration of overbank flow.

Vertebrates are usually conspicuous users of wetland habitats and resources and some may even influence riverine dynamics (Naiman et al. 1988). For example, beavers profoundly affect hydrologic regimes, nutrient dynamics, and vegetation characteristics of low order streams, and deer can negatively impact recruitment success of plants. Wetlands are also generally considered to support a richer fauna than adjacent upland communities, and many species that exploit mainly upland habitats require wetlands for some important life requisite. Waterfowl control the density of aquatic macrophytes and invertebrate assemblages. Fish feed on invertebrates and other fishes. Small rodents and birds play an important role in seed dispersal and interactions between vegetation and mycorrhizal dynamics.

The landscape-level diversity of riverine wetlands is developed and maintained largely through main channel hydrologic processes. Natural disturbances are often significant in maintaining high vertebrate diversity, particularly in high-energy riverine systems. Natural or anthropogenic factors that decrease wetland heterogeneity in either time or space often negatively affect animal species.

The goal in assessing this function is to compare reference and assessment site functions with respect to species composition and structure of vertebrate species associated with a wetland and the presence of necessary habitats to support wetland vertebrate fauna. Some vertebrate species (deer, game fishes, etc.) are managed for recreational extraction; others supply commercial fisheries. However, most vertebrates that depend upon wetlands provide no direct economic utility to man, but have great importance to overall ecosystem processes and to the maintenance of global biodiversity.

Description of variables

V_{FISH}, Distribution and abundance of resident and migratory fish. Riverine wetlands are important as spawning and rearing habitat for many fish species. Thus, fish are particularly sensitive to severed connections between a river and its floodplain wetlands. Migratory fish are also sensitive to alterations of seasonal hydrologic regimes because many migratory species have evolved to exploit an annual flooding pattern that allows them access to adjoining wetlands for spawning.

Fish are relatively well studied in North America, and the scientific literature contains much information on how to measure relative abundance, determine species richness, and calculate similarity indices. The fish density/ richness variable must be examined in the context of reference standards and hydrogeomorphic class (that is, one must be aware that reference standards usually vary regionally, among rivers of the same region and between different reaches of the same river).

For direct measures, a variable index score of 1.0 is assigned to assessment sites that show >75 percent similarity with their reference standard. Similarity can be determined by comparing density, species richness, or some index of similarity (see any ecology text for a discussion of such measures). A variable condition in which between 25 and 75 percent of its reference standard is met should score 0.5. Assessment sites that show 0 to 25 percent of their reference standard should be scored 0.1. Assessment sites devoid of fishes should receive a zero.

A direct measure of adult or juvenile fish population levels or species richness (number of species) can be expensive and logistically difficult to gather. However, many state game agencies have data on fish species abundances for river basins and for particular reaches of a river. This information can be used as an indirect measure of fish density or species richness if the data are current. An assessment that shows a close similarity between the assessment site and its reference standard should score a 1.0. A comparison that shows a moderate dissimilarity between the two should be given an index score of 0.5. If a comparison that shows that the assessment site and its reference standard are dissimilar, but suggests that there is potential for recovery of fish to the reference standard, a variable index score of 0.1 should be given. Assessment sites devoid of fish with no potential for recovery should receive a zero.

***V_{HERP}*, Distribution and abundance of herptiles.** Wetlands provide important habitat for some or all life stages of many herptile species (amphibians and reptiles). Amphibians are particularly sensitive to a loss of wetland habitat and changes in water chemistry or hydrologic regime, primarily because most amphibians require water to breed. Reptiles such as turtles, snakes, and alligators also depend upon a particular suite of factors (provided by wetlands) to maintain their populations.

Although herptiles are not as well studied as some other vertebrate groups (particularly birds and fishes), there are still many direct measurement (quantitative) techniques for estimating population size or comparing sites, including direct counts, tag/recapture methods, and encounters per unit time. The same technique should be used to compare assessment sites with reference standard, and all assessments should be calibrated against appropriate reference standard sites.

For direct measures, a variable index score of 1.0 is assigned to assessment sites that show >75 percent similarity with their reference standard. Similarity can be determined by comparing density, species richness, or some index of similarity (see any ecology text for a discussion of such measures). A variable condition in which between 25 and 75 percent of its reference standard is met should score 0.5. Assessment sites that show 0 to 25 percent of their reference standard should be scored 0.1. Assessment sites devoid of herptiles should receive a zero.

The collection of direct measurements may be costly and time consuming. However, one could use surrogate (indirect) measures to compare sites, such as presence of egg masses, tracks, calls, etc., or refer to reliable inventories collected recently at assessment and reference standard sites. For indirect measures, comparisons of recent species lists or abundance data can be used to derive similarity comparisons. An assessment using indirect measures that shows a close similarity between an assessment site and reference standards should score a 1.0. A comparison that shows a moderate dissimilarity between the two should be given an index score of 0.5. If a comparison shows that an assessment site and the reference standard have few similarities, but suggests that there is potential for recovery of herptiles to reference standard, a variable index score of 0.1 should be given. Assessment sites devoid of the herptiles with no potential for recovery should receive a zero.

V_{BIRD}, Distribution and abundance of resident and migratory birds. The abundance and species richness of birds is closely related to habitat complexity because birds have evolved to fill most available terrestrial niches. They partition habitats temporally (day versus night feeders), spatially (ground feeders, mid- and top-canopy feeders, etc.), and trophically (frugivores, insectivores, piscivores, etc.). Thus, birds are sensitive to alterations in the structure and function of wetland ecosystems. In addition, because birds are a well-studied group of vertebrate organisms, scientific literature is replete with information on how to measure relative abundance, determine species richness, and calculate similarity indices.

For direct measures, a variable index score of 1.0 is assigned to assessment sites that show >75 percent similarity with their reference standard. Similarity can be determined by comparing density, species richness, or some index of similarity (see ecology textbooks for a discussion of such measures). A variable condition in which between 25 and 75 percent of its reference standards is met should score 0.5. Assessment sites that show between 0 and 25 percent of their reference standard should be scored 0.1. Assessment sites devoid of birds should receive a zero.

Because direct measurements can be costly and time consuming, indirect measures may also be used to compare similarities in bird communities between assessment wetlands and their reference standard. Results from recent and reliable surveys can be used as indirect indicators of presence. Comparisons of recent species lists or abundance data can be used to derive similarity comparisons. A comparison that shows a large dissimilarity between the two, but with potential for recovery of the variable at an assessed site, should receive a 0.1 variable index score. Assessment sites devoid of birds with no potential for recovery should receive a zero.

V_{MAMM}, Distribution and abundance of permanent and seasonally resident mammals. Riverine wetlands provide habitat important to large and small mammals. Mammals are relatively well studied, and so there is abundant scientific literature on appropriate censusing techniques (mark/recapture, visual counts, etc.). Wide-ranging mammals (e.g., deer and bear) use wetlands as riparian corridors for foraging, cover, rest, and water. In arid regions, riparian zones are several degrees cooler during the day than surrounding uplands, and mammals often cool off and rest in such areas during midday.

Many small mammals are permanent residents of riverine wetlands, and in many hydrogeomorphic settings, more small mammals (in numbers and species) inhabit wetlands than surrounding upland areas. As is true for birds, mammals partition temporally, spatially, and trophically. Thus, mammals are sensitive to alterations in the structure and function of wetland ecosystems. In addition, because mammals are a well studied group, there is ample scientific literature on how to measure relative abundances, determine species richness, and calculate similarity indices.

For direct measures, a variable index score of 1.0 is assigned to assessment sites that show >75 percent similarity to the reference standard. Similarity can be determined by comparing density, species richness, or some index of similarity (see ecology textbooks for a discussion of such measures). A variable condition in which between 25 and 75 percent of its reference standards is met should score 0.5. Assessment sites that show between 0 and 25 percent of their reference standard should be scored 0.1. Assessment sites devoid of mammals should receive a zero.

Because direct measurement can be costly and time consuming, indirect measures may also be used to compare similarities in mammal communities at assessment wetlands and reference sites. Results from recent and reliable surveys or indirect indicators of presence and activity (burrows, scat, tracks, kills, browsed plants, etc.) can be used. Comparisons of recent species lists or abundance data can be used to derive similarity comparisons. If an assessment using indirect measures shows a close similarity between an assessment site and its reference standard, a score of 1.0 should be assigned. A comparison that shows a moderate dissimilarity between the two should given an index score of 0.5. If a comparison that shows that an assessment site and reference standard have few similarities, but suggests that there is potential for recovery of mammals to its reference standard, a variable index score of 0.1 should be given. Assessment sites devoid of mammals with no potential for their recovery should receive a zero.

V_{BEAV}, Abundance of beaver. Beaver have profound effects upon riverine wetlands, and thus are treated here separately from the other mammals. Beaver effects are manifest through virtually all of the other wetland functions, from dynamics of surface water storage to nutrient cycling to characteristics of the plant community. Beaver activity can be measured in various ways, but direct observation and individual counts provide the best empirical basis for assessment.

This variable should not be used if beaver are not locally available in the reference domain and if streams with beaver ponds are separated as a distinct subclass for assessment.

If direct measure of beaver abundance is >75 percent of its reference standard, an index value of 1.0 is given. If an assessment site condition is between 75 and 25 percent of its reference standard, an index value of 0.5 should be recorded. If an assessment site condition is between 0 and 25 percent of its reference standard, an index value of 0.1 should be given. If there is no evidence of beaver in the wetland area, a value of zero should be given.

Indirect measures of the presence and activity of beavers can be made. Evidence based on aerial photographs of beaver dams and lodges, or direct observation of these indicators along with cut plants, scat, or trails provides strong inference that beaver activity is occurring in a wetland. If the strength of those indicators is similar to that observed in reference standard wetlands, an index score of 1.0 should be given. If these indirect measures are reduced in frequency from that of their reference standard, a score of 0.5 should be given. If there is no evidence of beaver activity in a wetland, but there is potential for recovery to reference standard levels, a score of 0.1 should be given. If, however, there is no evidence of beaver activity and no potential for recovery, a score of zero is given.

Care must be taken in dealing with the assessment of wetlands modified by beaver because of their capacity to greatly alter hydrology, biogeochemistry, and habitat conditions of free-flowing streams and adjacent wetlands and uplands. If reference standards are to include beaver, provisions must be made to accommodate the condition in one of at least two possible ways. One option is to develop reference sets for beaver ponds separate from riverine wetland reaches not directly affected by the dams. Another is to try to encompass ponded and unimpounded reaches with the reference set, although this violates the goal of homogeneous conditions in assessment areas.

Index of function

The variables diversity and density of permanent and seasonally resident fishes (V_{FISH}), distribution and abundance of permanent and seasonally resident herptiles (V_{HERP}), distribution and abundance of resident and migratory avifauna (V_{BIRD}), diversity and abundance of permanent and seasonally resident mammals (V_{MAMM}), and abundance of beaver (V_{BEAV}) are used to assess the function Maintaining Distribution and Abundance of Vertebrates. Each indicator, whether determined via direct or indirect measures, must be scaled to a suite of reference wetlands and conditions appropriate for the physiographic region wetland class.

With beaver ponds:

$$Index\ of\ Function = (V_{FISH} + V_{HERP} + V_{BIRD} + V_{MAMM} + V_{BEAV})/5$$

Without beaver ponds:

$$Index\ of\ Function = (V_{FISH} + V_{HERP} + V_{BIRD} + V_{MAMM})/4$$

Each variable is assumed to be of equal importance in contributing to the function under reference standard conditions.

Documentation

MAINTAIN DISTRIBUTION AND ABUNDANCE OF VERTEBRATES

Definition: The capacity of a wetland to maintain characteristic density and spatial distribution of vertebrates (aquatic, semi-aquatic, and terrestrial) that utilize wetlands for food, cover, rest, and reproduction.

Effects Onsite: Disperses seeds throughout a site, pollinates flowers (bats), aerates the soil and coarse woody debris with tunnels, and alters hydroperiod and light regime (beavers, muskrats).

Effects Offsite: Disperses seeds between sites, pollinates flowers (bats), provides food (energy) for predators, alters hydroperiod and light regime (beavers, muskrats), and alters downstream flows.

Model Variables	Direct Measure	Indirect Measure	Index of Variable
V_{FISH}: Distribution and abundance of resident and migratory fish	Similarity index for species composition and abundance ≥75% of reference standard.	Surrogate measurements (e.g., egg masses, larval and fry stages, and adults) similar to reference standard.	1.0
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	Above indicators much less than reference standard.	0.5
	Similarity index for species composition and abundance between 0% and 25% of reference standard.	No evidence of indicators above, but potential for habitat recovery.	0.1
	No fish or evidence of fish found.	No evidence of indicators above, and no potential for habitat recovery.	0.0

V_{HERP}: Distribution and abundance of herptiles	Similarity index for species composition and abundance ≥75% of reference standard.	Surrogate measurements (e.g., egg masses, tracks, calls, larval stages, skins, skeletons) similar to reference standard.	1.0
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	Evidence of indicators as above, but less than reference standard.	0.5
	Similarity index for species composition and abundance between 0% and 25% of reference standard.	No evidence of above indicators, but potential for habitat recovery.	0.1
	No herptiles or evidence of herptiles found.	No visual evidence of above indicators and no potential for habitat recovery.	0.0
V_{BIRD}: Distribution and abundance of resident and migratory birds	Similarity index for species composition and abundance ≥75% of reference standard.	Surrogate measure (e.g., nests, tracks, calls, feathers, skeletons) similar to reference standard.	1.0
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	Evidence of above indicators, but less than reference standard.	0.5
	Similarity index for species composition and abundance between 0% and 25% of reference standard.	No evidence of above indicators, but potential for recovery of habitat to reference standard.	0.1
	No birds or evidence of birds found.	No evidence of above indicators, and no potential for recovery of habitat.	0.0
V_{MAMM}: Distribution and abundance of permanent and seasonally resident mammals	Similarity index for species composition and abundance ≥75% of reference standard.	Visual evidence of mammals (e.g., trails, scats, kills, presence of prey species, burrows, browsed plants) similar to reference standard.	1.0
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	As above, but less than reference standard.	0.5
	Similarity index for species composition and abundance between 0% and 25% of reference standard.	No visual evidence of mammal indicators, but potential for recovery of mammal habitat.	0.1
	No mammals or evidence of mammals found and no potential for recovery of habitat to reference standard.	No visual evidence of mammal indicators, but no potential for recovery of mammal habitat.	0.0
V_{BEAV}: Beaver abundance	Abundance ≥75% of reference standard.	Surrogate measure (e.g., recent aerial photographs, presence of active and abandoned lodges and dams, cut and chewed plants, scat, trails) similar to reference standard.	1.0

V_{BEAV}: (Concluded)	Abundance between 25% and 75% of reference standard.	As above, but indicators less than reference standard.	0.5
	Abundance between 0% and 25% of reference standard.	No evidence of above indicators, but potential for recovery of habitat exists.	0.1
	No beaver or evidence of beaver found.	No evidence of above indicators and no potential for recovery of beaver habitat.	0.0

With beaver ponds:

$$Index\ of\ Function = (V_{FISH} + V_{HERP} + V_{BIRD} + V_{MAMM} + V_{BEAV})/5$$

Without beaver ponds:

$$Index\ of\ Function = (V_{FISH} + V_{HERP} + V_{BIRD} + V_{MAMM})/4$$

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Appendix A
Definitions of Variables and Functions for Riverine Wetlands

Variables

V_{AQINVT} Aquatic invertebrates: Composition and abundance of invertebrates that live in aquatic habitats.

V_{BEAV} Beaver: Abundance of beaver.

V_{BIRD} Birds: Distribution and abundance of resident and migratory birds.

V_{BTREE} Tree basal area: Basal area or biomass of trees.

V_{CANOPY} Canopy cover: Measure of the percent closure of the canopy.

V_{COMP} Species composition: Dominant species for tree, shrub, and herb strata.

V_{CONTIG} Contiguous vegetation cover: Contiguous cover and corridors between wetland and upland, between channels, and between upstream-downstream areas.

V_{CWD} Coarse woody debris: Volume of dead and down trees and limbs larger than an appropriately defined diameter.

V_{DTREE} Tree density: Density of large-diameter canopy trees.

V_{DURAT} Duration of overbank flow: Duration of connection between channel and floodplain.

V_{FISH} Fish: Distribution and abundance of resident and migratory fishes.

V_{FREQ} Frequency of overbank flow: Frequency or recurrence interval at which bank-full discharge is exceeded.

V_{FWD} Fine woody debris: Small limbs, twigs, and leaves.

V_{GAPS} Canopy gaps: Density or percent cover of openings (gaps) in forest canopy resulting from tree fall.

V_{HERB} Herbaceous density, biomass, or cover: The density, biomass, or percentage cover of herbaceous plants.

V_{HERP} Herptiles: Distribution and abundance of herptiles.

V_{INUND} Depth of inundation: Average flooding depth during overbank flooding events.

V_{LINVT} Litter invertebrates: Composition and abundance of invertebrates that live in litter.

V_{LOGS} Logs in several stages of decomposition: Biomass of logs in each of several decay classes.

V_{MACRO} Macrotopographic relief: Large-scale relief in the form of oxbows, meander scrolls, abandoned channels, and backswamps.

V_{MAMM} Mammals: Distribution and abundance of permanent and seasonally resident mammals.

V_{MATUR} Abundance of very mature trees. Density of very mature and dying trees.

V_{MICRO} Microtopographic complexity: Small-scale topographic relief in the form of pit-and-mound or hummock-and-hollow patterns.

V_{MICROB} Surfaces available for microbial activity: Measure of organic surfaces (litter, plant material, other organic matter) available as platforms for microbial growth.

V_{ORGAN} Organic matter in wetland: Dissolved and particulate organic matter (live and dead).

V_{PATCH} Vegetation patchiness: Spatial heterogeneity of vegetation-types.

V_{PORE} Soil pore space: Pore space available for storing water.

V_{PROD} Aerial net primary production: Aerial net primary production, measured as leaf area index, aboveground biomass, etc.

V_{REDVEL}	Reduction in flow velocity: Reduction in flow through a wetland during an overbank flooding event.
V_{REGEN}	Regeneration from seedlings, saplings, clonal shoots: Comparison of dominant species list between reproductive stages of assessment site and mature stages of reference standard.
V_{SEDIM}	Retained sediments: Presence of natural levees of coarse sediments near stream and fine sediments on floodplain.
V_{SHRUB}	Shrub density, biomass, or cover: Density, biomass, or cover of woody understory plants (shrubs and saplings).
V_{SINVT}	Soil invertebrates: Composition and abundance of invertebrates that live in soil.
V_{SNAGS}	Snags: Density or biomass of standing dead trees.
V_{SORPT}	Sorptive properties of soils: Similarity of soils to reference standard with respect to texture, organic carbon content, and other properties.
V_{STRATA}	Number and attributes of vertical strata: Direct count of the number of vegetation strata.
V_{SUBCON}	Subsurface hydraulic connections: Subsurface pathways that connect portions of the wetland with the stream channel.
V_{SUBIN}	Subsurface flow into wetland: Subsurface flow into a wetland via interflow and return flow.
V_{SUBOUT}	Subsurface flow out of wetland: Subsurface flow from a wetland to aquifer or to base flow.
$V_{SURFCON}$	Surface hydraulic connections: Hydraulic connections between stream channel and floodplain (usually large-scale features on high-energy rivers).
V_{SURFIN}	Surface inflow to the wetland: Overland flow from upland to wetland as indicated by rills and rearranged litter on upland slopes leading to wetland.
V_{SURWAT}	Indications of surface water presence: Presence or indication that surface is inundated for at least 1 week.
V_{TURNOV}	Annual turnover of detritus: Standing stocks of detritus (snags, coarse woody debris, and humus).

V_{WTF} Fluctuation of water table: Change in water table elevation with rises usually caused by precipitation or flooding events and falls due to evapotranspiration and drainage.

Hydrologic Functions

Dynamic surface water storage. Capacity of a wetland to detain moving water from overbank flow for a short duration when flow is out of the channel; associated with moving water from overbank flow and/or upland surface water inputs by overland flow or tributaries.

Long-term surface water storage. The capability of a wetland to temporarily store (retain) surface water for long durations; associated with standing water not moving over the surface. Water sources may be overbank flow, overland flow and/or channelized flow from uplands, or direct precipitation.

Energy dissipation. Allocation of the energy of water to other forms as it moves through, into, or out of the wetland as a result of roughness associated with large woody debris, vegetation structure, micro- and macrotopography, and other obstructions.

Subsurface water storage. Availability of water storage beneath the wetland surface; storage capacity becomes available due to periodic drawdown of water table.

Moderation of groundwater flow or discharge. Capacity of a wetland to moderate rate of groundwater flow or discharge from upgradient sources or from groundwater discharge within a wetland.

Biogeochemical Functions

Nutrient cycling. Abiotic and biotic processes that convert elements from one form to another; primarily recycling processes.

Removal of imported elements and compounds. The removal of imported nutrients, contaminants, and other elements or compounds.

Retention of particulates. Deposition and retention of inorganic and organic particulates ($>0.45\ \mu m$) from the water column, primarily through physical processes.

Organic carbon export. Export of dissolved and particulate organic carbon from the wetland. Mechanisms include leaching, flushing, displacement, and erosion.

Habitat Functions

Maintain characteristic plant community. Species composition and physical characteristics of living plant biomass. The emphasis is on the dynamics and structure of the plant community as revealed by the species of trees, shrubs, seedlings, saplings, and herbs and by the physical characteristics of the vegetation.

Maintain characteristic detrital biomass. The process of production, accumulation, and dispersal of dead plant biomass of all sizes. Sources may be onsite or upslope and upgradient.

Maintain spatial structure of habitat. The capacity of a wetland to support animal populations and guilds by providing heterogeneous habitats.

Maintain interspersion and connectivity. The capacity of a wetland to permit aquatic organisms to enter and leave the wetland via permanent or ephemeral surface channels, overbank flow, or unconfined hyporheic gravel aquifers. The capacity of the wetland to permit access of terrestrial or aerial organisms to contiguous areas of food and cover.

Maintain distribution and abundance of invertebrates. The capacity of the wetland to maintain the density and spatial distribution of invertebrates (aquatic, semi-aquatic, and terrestrial).

Maintain distribution and abundance of vertebrates. The capacity of the wetland to maintain the density and spatial distribution of vertebrates (aquatic, semi-aquatic, and terrestrial).

Appendix B
Relationship Between Variables and Wetland Functions

Hydrologic Functions

Variables	Dynamic	Long-Term	Dissipation	Subsurface	Moderation
1. V_{BTREE}	X	O	O	O	O
2. V_{CWD}	X	O	X	O	O
3. V_{DTREE}	X	O	X	O	O
4. V_{FREQ}	X	O	X	O	O
5. V_{INUND}	X	O	O	O	O
6. V_{MACRO}	O	X	X	O	O
7. V_{MICRO}	X	O	X	O	O
8. V_{PORE}	O	O	O	X	O
9. V_{REDVEL}	O	O	X	O	O
10. V_{SHRUB}	X	O	O	O	O
11. V_{SUBIN}	O	O	O	O	X
12. V_{SUBOUT}	O	O	O	O	X
13. V_{SURWAT}	O	X	O	O	O
14. V_{WTF}	O	O	O	X	O

Note: Dynamic = Dynamic Surface Water Storage, Long-term = Long-Term Surface Water Storage, Dissipation = Energy Dissipation, Subsurface = Subsurface Water Storage, Moderation = Moderation of Groundwater Flow or Discharge.

Variables

1. V_{BTREE} = Tree basal area
2. V_{CWD} = Coarse woody debris
3. V_{DTREE} = Tree density
4. V_{FREQ} = Frequency of overbank flow
5. V_{INUND} = Average depth of inundation
6. V_{MACRO} = Macrotopographic relief
7. V_{MICRO} = Microtopographic complexity
8. V_{PORE} = Soil pore space
9. V_{REDVEL} = Reduction in flow velocity
10. V_{SHRUB} = Shrub density, biomass, or cover
11. V_{SUBIN} = Subsurface flow into wetland
12. V_{SUBOUT} = Subsurface flow out of wetland
13. V_{SURWAT} = Indications of surface water presence
14. V_{WTF} = Fluctuation of water table

Biogeochemical Functions

Variables	Nutrient	Removal	Particulate	Organic
1. V_{BTREE}	O	X	X	O
2. V_{CWD}	O	O	X	O
3. V_{DTREE}	O	O	X	O
4. V_{FREQ}	O	X	X	X
5. V_{HERB}	O	O	X	O
6. V_{MICRO}	O	X	X	O
7. V_{MICROB}	O	X	O	O
8. V_{ORGAN}	O	O	O	X
9. V_{PROD}	X	O	O	O
10. V_{SEDIM}	O	O	X	O
11. V_{SHRUB}	O	O	X	O
12. V_{SORPT}	O	X	O	O
13. V_{SUBIN}	O	X	O	X
14. V_{SURCON}	O	O	O	X
15. V_{SURFIN}	O	X	X	X
16. V_{TURNOV}	X	O	O	O

Note: Nutrient = Nutrient cycling, Removal = Removal of imported elements and compounds, Particulates = Retention of particulates, Organic = Organic carbon export.

Variables

1. V_{BTREE} = Tree basal area
2. V_{CWD} = Coarse woody debris
3. V_{DTREE} = Tree density
4. V_{FREQ} = Frequency of overbank flow
5. V_{HERB} = Herbaceous density, biomass, or cover
6. V_{MICRO} = Microtopographic complexity
7. V_{MICROB} = Surfaces available for microbial activity
8. V_{ORGAN} = Organic matter in wetland
9. V_{PROD} = Aerial net primary production
10. V_{SEDIM} = Retained sediments
11. V_{SHRUB} = Shrub density, biomass, or cover
12. V_{SORPT} = Sorptive properties of soils
13. V_{SUBIN} = Subsurface inflow into wetland
14. $V_{SURFCON}$ = Surface hydraulic connections
15. V_{SURFIN} = Surface inflow to wetland
16. V_{TURNOV} = Annual turnover of detritus

Habitat Functions

Variables	Plant	Detrital	Habitat	Interspersion	Invertebrates	Vertebrates
1. V_{AQINVT}	O	O	O	O	X	O
2. V_{BEAV}	O	O	O	O	O	X
3. V_{BIRD}	O	O	O	O	O	X
4. V_{BTREE}	X	O	O	O	O	O
5. V_{CANOPY}	X	O	O	O	O	O
6. V_{COMP}	X	O	O	O	O	O
7. V_{CONTIG}	O	O	O	X	O	O
8. V_{CWD}	O	X	O	O	O	O
9. V_{DURAT}	O	O	O	X	O	O
10. V_{DTREE}	X	O	O	O	O	O
11. V_{FISH}	O	O	O	O	O	X
12. V_{FREQ}	O	O	O	X	O	O
13. V_{FWD}	O	X	O	O	O	O
14. V_{GAPS}	O	O	X	O	O	O
15. V_{HERP}	O	O	O	O	O	X
16. V_{LINVT}	O	O	O	O	X	O
17. V_{LOGS}	O	X	O	O	O	O
18. V_{MAMM}	O	O	O	O	O	X
19. V_{MATUR}	O	O	X	O	O	O
20. V_{MICRO}	O	O	O	X	O	O
21. V_{PATCH}	O	O	X	O	O	O
22. V_{REGEN}	X	O	O	O	O	O
23. V_{SINVT}	O	O	O	O	X	O
24. V_{SNAGS}	O	X	X	O	O	O
25. V_{STRATA}	O	O	X	O	O	O
26. V_{SUBCON}	O	O	O	X	O	O
27. $V_{SURFCON}$	O	O	O	X	O	O

Note: Plant = Maintain Characteristic Plant Community, Detrital = Maintain Characteristic Detrital Biomass, Habitat = Maintain Spatial Structure of Habitat, Interspersion = Maintain Habitat Interspersion and Connectivity, Invertebrates = Maintain Distribution and Abundance of Invertebrates, Vertebrates = Maintain Distribution and Abundance of Vertebrates.

Variables

1. V_{AQINVT} = Aquatic invertebrates
2. V_{BEAV} = Beaver
3. V_{BIRD} = Birds
4. V_{BTREE} = Tree basal area
5. V_{CANOPY} = Canopy cover
6. V_{COMP} = Species composition
7. V_{CONTIG} = Contiguous vegetation cover
8. V_{CWD} = Coarse woody debris
9. V_{DTREE} = Tree density
10. V_{DURAT} = Duration of overbank flow
11. V_{FISH} = Fish
12. V_{FREQ} = Frequency of overbank flow
13. V_{FWD} = Fine woody debris
14. V_{GAPS} = Canopy gaps
15. V_{HERP} = Herptiles
16. V_{LINVT} = Litter invertebrates
17. V_{LOGS} = Logs in several stages of decomposition
18. V_{MAMM} = Mammals
19. V_{MATUR} = Abundance of very mature trees
20. V_{MICRO} = Microtopographic complexity
21. V_{PATCH} = Vegetation patchiness
22. V_{REGEN} = Regeneration from seedlings, saplings, clonal shoots
23. V_{SINVT} = Soil invertebrates
24. V_{SNAGS} = Snags
25. V_{STRATA} = Number of attributes of vertical strata
26. V_{SUBCON} = Subsurface hydraulic connections
27. $V_{SURFCON}$ = Surface hydraulic connections

Appendix C
Field Forms—Tally Sheets and Synopses

Tally Sheet for Dynamic Surface Water Storage

Site Location ______________________________

Reference Domain ______________________________

Team ______________________________

Date ______________________________

V_{FREQ}: Frequency of Overbank Flow

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0	1.0	
	As above, but somewhat greater or less than reference standard.	0.5	0.5	
	Above indicators absent but related indicators suggest overbank flow may occur.	0.1	0.1	
	Indicators absent and/or there is evidence of alteration affecting variable.	0.0	0.0	
Direct	Gauge data (1.5) yr return interval similar to reference standard.	1.0	1.0	
	Gauge data (>2 or <1) yr return interval; slight departure from reference standard.	0.5	0.5	
	Gauge data show extreme departure from reference standard.	0.1	0.1	
	Gauge data indicate no flooding from overbank flow.	0.0	0.0	
	Index of V_{FREQ} =			

V_{INUND}: Average Depth of Inundation

Method (choose one)	Measure Relative to the Reference Standard	Pre Project	Post Project	Comments and Notes
Indirect	Height of water stains and other indicators of water depth (ice scars, bryophyte lines, drift and/or wrack lines, etc.) between 75% and 125% of reference standard.	1.0	1.0	
	Height of water stains and other indicators of water depth (ice scars, bryophyte lines, drift and/or wrack lines, etc.) <75% of reference standard.	0.5	0.5	
	Above indicators absent but related indicators suggest variable may be present.	0.1	0.1	
	Indicators absent and/or evidence of alteration affecting the variable.	0.0	0.0	
Direct	Gauge data indicate that depth is between 75% and 125% that of reference standard.	1.0	1.0	
	Gauge data indicate depth is <75% or >125% of reference standard.	0.5	0.5	
	Gauge data indicate infrequent or minor over-bank flooding relative to reference standard.	0.1	0.1	
	Gauge data indicate flooding does not occur.	0.0	0.0	
	Index of V_{INUND} =			

V_{MICRO}: Microtopographic Complexity

Method (choose one)	Measure Relative to the Reference Standard	Pre Project	Post Project	Comments and Notes
Indirect	Visual estimate indicates that microtopographic complexity (MC) is >75% and <125% of reference standard.	1.0	1.0	
	Visual assessment confirms MC is present, but somewhat less than reference standard.	0.5	0.5	
	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1	0.1	
	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0	0.0	
Direct	Microtopographic complexity (MC) measured (surveyed) shows MC >75% to <125% of reference standard.	1.0	1.0	
	Measured MC is between 25% and 75% that of reference standard.	0.5	0.5	
	Measured MC between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No MC at assessed site or natural substrate replaced by artificial surface; no restoration possible.	0.0	0.0	
	Index of V_{MICRO} =			

V_{SHRUB}: Shrub Density

Method (choose one)	Measure Relative to the Reference Standard	Pre Project	Post Project	Comments and Notes
Indirect	Visual estimate of shrubs indicates site is similar (>75%) to reference standard.	1.0	1.0	
	Visual estimate of shrubs indicates site is between 25% and 75% that of reference standard.	0.5	0.5	
	Shrubs sparse or absent relative to reference standard; restoration possible.	0.1	0.1	
	Shrubs absent; restoration not possible.	0.0	0.0	
Direct	Shrub abundance >75% that of reference standard.	1.0	1.0	
	Shrub abundance between 25% and 75% that of reference standard.	0.5	0.5	
	Shrub abundance between 0% and 25% that or reference standard.	0.1	0.1	
	Shrubs absent; restoration not possible.	0.0	0.0	
	Index of V_{SHRUB} =			

V_{BTREE}: Tree Basal Area

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stage of succession similar to reference standard.	1.0	1.0	
	Stage of succession departs significantly from reference standard.	0.5	0.5	
	Stage of succession at extreme departure from reference standard.	0.1	0.1	
	Stand cleared without potential for recovery.	0.0	0.0	
Direct	Basal area or biomass is greater than 75% of reference standard.	1.0	1.0	
	Basal area or biomass between 25% and 75% of reference standard.	0.5	0.5	
	Basal area or biomass between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No trees present; restoration not possible.	0.0	0.0	
	Index of V_{BTREE} =			

V_{DTREE}: Tree Density

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stage of succession similar to reference standard.	1.0	1.0	
	Stage of succession departs significantly from reference standard.	0.5	0.5	
	Stage of succession at extreme departure from reference standard; restoration possible.	0.1	0.1	
	Stand cleared; no restoration possible.	0.0	0.0	
Direct	Measured or estimated tree density between 75% and 125% of reference standard.	1.0	1.0	
	Tree density is between 25% and 75%, or between 125% and 200% of reference standard.	0.5	0.5	
	Tree density is between 0% and 25% or greater than 200% of reference standard; restoration possible.	0.1	0.1	
	No trees are present; restoration not possible.	0.0	0.0	
	Index of V_{DTREE} =			

V_{CWD}: Coarse Woody Debris

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Average diameters and lengths of CWD is >75% and <125% of reference standard.	1.0	1.0	
	Average diameters and lengths of CWD is between 25% and 75% that of reference standard.	0.5	0.5	
	Average diameters and lengths of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No CWD present; restoration not possible.	0.0	0.0	
Direct	Biomass of CWD is >75% and <125% of reference standard.	1.0	1.0	
	Biomass of CWD is between 25% and 75% that of reference standard.	0.5	0.5	
	Biomass of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No CWD present; restoration not possible.	0.0	0.0	
	Index of V_{CWD} =			

Calculate Change in Function (Transfer indices of variables to this table)

Condition	Indices of Variables							Index of Function = $[V_{FREQ} \times (V_{INUND} + V_{MICRO} + V_{SHRUB} + V_{BTREE}$ or $V_{DTREE} + V_{CWD})/5]^{1/2}$
	V_{FREQ}	V_{INUND}	V_{MICRO}	V_{SHRUB}	V_{BTREE}	V_{DTREE}	V_{CWD}	
a) Pre-Project/ Mitigation								
b) Post-Project/ Mitigation								
Change Due to Project (subtract b from a)								

Synopsis of Dynamic Surface Water Storage

Definition. Capacity of a wetland to detain moving water from overbank flow for a short duration when flow is out of the channel; associated with moving water from overbank flow and/or upland surface water inputs by overland flow or tributaries.

Effects onsite. Replenish soil moisture; import/export of materials (i.e., sediments, nutrients, contaminants); import/export of plant propagules; conduit for aquatic organisms to access wetland for feeding, recruitment, etc.

Effects offsite. Reduce downstream peak discharge and streamflow volume; delay downstream delivery of peak discharges; and improve water quality.

Description of indicators and variables.

V_{FREQ}, ***Frequency of overbank flow.*** Without a supply of water via overbank flow, a riverine wetland cannot store flood water. If appropriate to the reference domain, a wetland that is flooded annually scores 1.0; a greater or lesser frequency would score less than 1.0. If overbank flow does not occur, the score is zero. Other sources, such as overland flow or tributary flow from upland areas, must be treated separately, in a manner that is appropriate to the reference standard.

V_{INUND}, ***Average depth of inundation.*** Any increase in flooding depth at a given site leads to a greater volume of stored water. However, a greater depth of inundation may result in shorter detention times per unit volume because flow-through rates increase.

V_{MICRO}, ***Microtopographic complexity.*** Microtopographic complexity is an expression of the tortuosity of flow pathways. The greater the complexity (roughness), the more the resistance to flow and water will be detained for longer periods of time.

V_{SHRUB}, V_{BTREE} *or* V_{DTREE}, ***Roughness of vegetation surfaces.*** Frictional of water passes over surfaces creates turbulent flow and reduced velocities, both of which are conducive to sediment deposition. Here, three variables are scaled independently. However, Manning's coefficients have been developed for site-specific data in order to attempt to provide quantitative relationships between roughness and wetland structure.

If available or if it can be estimated reliably, Manning's roughness coefficient may be substituted as an aggregate of variables V_{MICRO}, $_{SHRUB}$, $_{BTREE}$ *or* $_{DTREE}$, *and* $_{CWD}$.

V_{CWD}**, *Coarse woody debris.*** Coarse woody debris creates resistance to flow during flooding; resistance extends detention times, reduces flow velocity, and increases short-term water storage.

$$Index\ of\ Function = [V_{FREQ} \times (V_{INUND} + V_{MICRO} + V_{SHRUB} + V_{BTREE}\ or\ V_{DTREE} + V_{CWD})/5]^{1/2}$$

*Option 2: If Manning's roughness coefficient is used to aggregate variables V_{MICRO}, V_{SHRUB}, V_{BTREE} or V_{DTREE}, and V_{CWD}

$$Index\ of\ Function = [V_{FREQ} \times (V_{INUND} + V_{MICRO,\ SHRUB,\ BTREE\ or\ DETREE\ and\ CWD})/2]^{1/2}$$

Tally Sheet for Long-Term Surface Water Storage

Site Location ______________________________

Reference Domain ______________________________

Team ______________________________

Date ______________________________

V_{SURWAT}: Indicators of Surface Water Presence

Method (choose one)	Measure Relative to the Reference Standard	Pre Project	Post Project	Comments and Notes
Indirect	Compared to regional reference standard: 1. Annual understory (grass and woody reproduction, etc., absent) or 2. High organic matter accumulation at soil surface or 3. Massive soil structure with low permeability and general lack of small roots in the surface soil horizon or 4. NRCS Hydrologic Soil Group C or D when soil series known.	1.0	1.0	
	As above, but below reference standard.	0.5	0.5	
	Above indicators absent but related indicators suggest variable may be present.	0.1	0.1	
	Indicators absent and/or there is evidence of alteration affecting variable.	0.0	0.0	
Direct	1. Gauge data indicate overbank flow sufficient to pond water or 2. Direct observation of ponded water or 3. Aerial photo evidence confirms flooding similar to reference standard.	1.0	1.0	
	Gauge data indicate no overbank flow; ponding minor or not evident; no evidence of flooding on aerial photos.	0.0	0.0	
	Index of V_{SURWAT} =			

V_{MACRO}: Macrotopographic Relief

Method (choose one)	Measure Relative to the Reference Standard	Pre Project	Post Project	Comments and Notes
Indirect	Oxbows, meander scrolls, abandoned channels, backswamps, etc., similar in magnitude to reference standard.	1.0	1.0	
	Indicators above much less developed than reference standard and area has a low surface gradient.	0.5	0.5	
	All above indicators absent and area has a moderate to steep gradient.	0.0	0.0	
Direct	1. Contour maps indicate gross relief and/or closed contours similar to reference standard or 2. Topographic survey shows relief similar to reference standard.	1.0	1.0	
	Maps and/or topographic survey indicate relief very dissimilar to reference standard.	0.0	0.0	
	Index of V_{MACRO} =			

Calculation of Change in Function (Transfer indices of variables to this table)

Condition	Indices of Variables		*Index of Function* = $(V_{SURWAT} + V_{MACRO})/2$
	V_{SURWAT}	V_{MACRO}	
a) Pre-Project/ Mitigation			
b) Post-Project/ Mitigation			
Change Due to Project (subtract b from a)			

Synopsis of Long-Term Surface Water Storage

Definition. The capability of a wetland to temporarily store (retain) surface water for long durations; associated with standing water not moving over the surface. Water sources may be overbank flow, overland flow and/or channelized flow from uplands, or direct precipitation.

Effects onsite. Replenishes soil moisture; removes sediments, nutrients, and contaminants; detains water for chemical transformations; maintains vegetative composition; maintains habitat for feeding, spawning, recruitment, etc., for pool species; and influences soil characteristics.

Effects offsite. Improves water quality; maintains base flow; maintains seasonal flow distribution; lowers the annual water yield; recharges surficial groundwater.

Description of indicators and variables.

V_{SURWAT}, ***Indicators of surface water presence.*** For long-term storage (considered to be longer than 1 week) to occur, water must be ponded in the wetland. This can be directly observed or determined from interpretation of site features that indicate water was ponded on the surface for long periods of time. Overbank flow is important to this variable, but ponding can occur and/or be sustained by precipitation, subsurface discharge, and surface discharge from riparian uplands.

V_{MACRO}, ***Macrotopographic relief.*** There must be sufficient macrotopographic relief, particularly when the stream has retreated to within its banks, to retain water for long periods of time. These features may be in the form of oxbows, meander scrolls, abandoned channels, pits and mounds, etc., with restricted outlets.

Index of function.

$$\textit{Index of Function} = (V_{SURWAT} + V_{MACRO})/2$$

Tally Sheet for Energy Dissipation

Site Location ______________________________
Reference Domain ______________________________
Team ______________________________
Date ______________________________

V_{REDVEL}: Reduction in Flow Velocity

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Sediment deposits, silt deposits on vegetation, buried root collars, stacked wracks of debris, etc., similar to reference standard.	1.0	1.0	
	Sediment scour, scoured root collars, large woody debris moved about; erosion of soil surface, etc., indicating less than reference standard.	0.5	0.5	
	Directionally bent vegetation, bare soil exposed (not sediment deposits), strongly departing from reference standard.	0.1	0.1	
	Strong evidence of severe site degradation by channel scour, exposed root masses, suggesting variable is absent.	0.0	0.0	
Direct	Velocity in wetland >75% of that expected in reference standard sites.	1.0	1.0	
	Less than 75% reduction in velocity relative to standard.	0.5	0.5	
	No reduction in velocity by direct measurement.	0.0	0.0	
	Index of V_{REDVEL} =			

V_{FREQ}: Frequency of Overbank Flow

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0	1.0	
	As above, but somewhat greater or less than reference standard.	0.5	0.5	
	Above indicators absent, but related indicators suggest overbank flow may occur.	0.1	0.1	
	Indicators absent and/or there is evidence of alteration affecting variable; restoration not possible.	0.0	0.0	
Direct	Gauge data (1.5) yr return interval within 75% and 125% of reference standard.	1.0	1.0	
	Gauge data (>2 or <1) yr return interval 25% to 75% or >125% of reference standard.	0.5	0.5	
	Gauge data show extreme departure from reference standard, e.g., 0% to 25%.	0.1	0.1	
	Gauge data indicate no flooding from overbank flow.	0.0	0.0	
	Index of V_{FREQ} =			

V_{MACRO}: Macrotopographic Relief

Method (choose one)	Measure Relative to the Reference Standard	Pre Project	Post Project	Comments and Notes
Indirect	Oxbows, meander scrolls, abandoned channels, backswamps, etc., similar in magnitude to reference standard.	1.0	1.0	
	Indicators above much less developed than reference standard, and area has a low surface gradient.	0.5	0.5	
	All above indicators absent and area has a moderate to steep gradient.	0.0	0.0	
Direct	1. Contour maps indicate gross relief and/or closed contours similar to reference standard or 2. Topographic survey shows relief similar to reference standard.	1.0	1.0	
	Maps and/or topographic survey indicate relief very dissimilar to reference standard.	0.0	0.0	
	Index of V_{MACRO} =			

V_{MICRO}: Microtopographic Complexity

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual estimate indicates that microtopographic complexity (MC) is >75% and <125% of reference standard.	1.0	1.0	
	Visual assessment confirms MC is present, but somewhat less than reference standard.	0.5	0.5	
	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1	0.1	
	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0	0.0	
Direct	Microtopographic complexity (MC) measured (surveyed) shows MC >75% to <125% of reference standard.	1.0	1.0	
	Measured MC is between 25% and 75% that of reference standard.	0.5	0.5	
	Measured MC between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No MC at assessed site or natural substrate replaced by artificial surface.	0.0	0.0	
	Index of V_{MICRO} =			

V_{DTREE}: Tree Density

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stage of succession similar to reference standard.	1.0	1.0	
	Stage of succession departs significantly from reference standard.	0.5	0.5	
	Stage of succession at extreme departure from reference standard; restoration possible.	0.1	0.1	
	Stand cleared; no restoration possible.	0.0	0.0	
Direct	Measured or estimated tree density is between 75% and 125% of reference standard.	1.0	1.0	
	Tree density is between 25% and 75% or between 125% and 200% of reference standard.	0.5	0.5	
	Tree density is between 0% and 25% or >200% of reference standard; restoration possible.	0.1	0.1	
	No trees are present; restoration not possible.	0.0	0.0	
	Index of V_{DTREE} =			

V_{CWD}: Coarse Woody Debris

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Average diameter and lengths of CWD is >75% and <125% that of reference standard.	1.0	1.0	
	Average diameter and lengths of CWD is between 25% and 75% that of reference standard.	0.5	0.5	
	Average diameter and lengths of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No CWD present; restoration not possible.	0.0	0.0	
Direct	Biomass of CWD >75% and <125% that of reference standard.	1.0	1.0	
	Biomass of CWD between 25% and 75% that of reference standard.	0.5	0.5	
	Biomass of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No CWD present; restoration not possible.	0.0	0.0	
	Index of V_{CWD} =			

Calculation of Change in Function (Transfer indices of variables to this table)

Conditions	Indices of Variables						*Index of Function* = $(V_{FREQ} \times V_{REDVEL})^{1/2}$ or *Index of Function* = $\{V_{FREQ} \times [(V_{MACRO} + V_{MICRO} + V_{DTREE} + V_{CWD})/4]\}^{1/2}$
	V_{FREQ}	V_{REDVEL}	V_{MACRO}	V_{MICRO}	V_{DTREE}	V_{CWD}	
a) Pre-Project/ Mitigation							
b) Post-Project/ Mitigation							
Change Due to Project (subtract b from a)							

Synopsis of Energy Dissipation

Definition. Allocation of the energy of water to other forms as it moves through, into, or out of the wetland as a result of roughness associated with large woody debris, vegetation structure, micro- and macrotopography, and other obstructions.

Effects onsite. Increases deposition of suspended material; increases chemical transformations and processing due to longer residence time.

Effects offsite. Reduces downstream peak discharge; delays delivery of peak discharges; improves water quality; reduces erosion of shorelines and floodplains.

Description of indicators and variables.

V_{FREQ}, ***Frequency of overbank flow.*** For energy to be dissipated by the wetland, water must enter the wetland. Overbank flow and dissipation of energy can result in better distribution of large woody debris and improved channel stability.

V_{REDVEL}, ***Reduction in flow velocity.*** A critical variable in energy dissipation of flowing water energy. As depth of inundation increases, velocity decreases. Further decreases result from sinuosity of channels and other shape factors of the wetland. Indications of velocity reduction are best made through "cause and effect" relationships, such as scour holes around trees, sediment deposits in the form of small bars, buried root collars, development of wrack lines, etc.

V_{MICRO}, ***Microtopographic complexity.*** Microtopographic complexity is an expression of the tortuosity of flow pathways. The greater the complexity (roughness), the more the resistance to flow, and the higher the dissipation of energy.

V_{MACRO}, ***Macrotopographic relief.*** There must be sufficient macrotopographic relief, particularly when the stream has retreated to within its banks, to retain water for long periods of time. These features may be in the form of oxbows, meander scrolls, abandoned channels, pits and mounds, etc., with restricted outlets.

V_{DTREE}, ***Tree density.*** If both tree density at the assessment site is 75 to 125 percent of reference standards, it may be assumed that the site is stable and a score of 1.0 is given. A score of 0.5 is assigned if the range is either 25 to 75 percent or 125 to 200 percent. Densities beyond the foregoing ranges (i.e., higher or lower) are assigned 0.1. The absence of tree species receives a 0.0. Indirect measures of density and basal area should not be used unless it is impossible to obtain a direct measure. The only acceptable indirect measure should be published data or data that have not been published but can be verified.

V_{CWD}, ***Coarse woody debris.*** If the density of fallen logs at the assessment site is >75 percent of the reference standard, a score of 1.0 is given. Comparisons that are <75 percent are scored as 0.5 or 0.1 depending on whether the assessment site has >25 to <75 percent or >1 to <25 percent of the density relative to the reference standard, respectively. If the assessment site has no coarse woody debris on the soil surface, a variable score of 0.0 is given. The only appropriate indirect measure would be information compiled from recent aerial photographs, taken during the leafless season. There is no appropriate indirect measure if the site is dominated by evergreen trees.

$$\textit{Index of Function} = [V_{FREQ} \times V_{REDVEL}]^{1/2} \; \textit{or}$$

$$\textit{Index of Function} = \{V_{FREQ} \times [(V_{MACRO} + V_{MICRO} + V_{DTREE} + V_{CWD})/4)]\}^{1/2}$$

If Manning's n is used as a surrogate for the site roughness factors,

$$\textit{Index of Function} = [V_{FREQ} \times (V_{MACRO,\ MICR,\ DTREE,\ CWD})]^{1/2}$$

It is assumed that each of the combined roughness variables, frequency of overbank flow, and reduction of flow velocity are equally important in maintaining the function in reference standards.

Tally Sheet for Subsurface Water Storage

Site Location ______________________________

Reference Domain ______________________________

Team ______________________________

Date ______________________________

V_{PORE}: Soil Pore Space Available for Storage

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Use direct measure.	1.0	1.0	
	Use direct measure.	0.5	0.5	
	1. Algae in pore spaces, 2. Films on ped faces, or 3. Soil compacted or replaced by substrate with negligible pore space.	0.1	0.1	
	Soil compacted or replaced by substrate with negligible pore space.	0.0	0.0	
Direct	Example: The reference standard is sandy loam to coarser texture soil with good structure.	1.0	1.0	
	Soil textures finer than sandy loam.	0.5	0.5	
	Soil saturated to surface or ponded for long durations during the growing season.	0.1	0.1	
	Soil saturated to surface or ponded throughout the year.	0.0	0.0	
	Index of V_{PORE} =			

V_{WFT}: Fluctuation of Water Table

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Example: Water table falls rapidly to 15-30 cm of surface.	1.0	1.0	
	Water table falls slowly and/or to a depth of 15 cm.	0.5	0.5	
	Soils stay nearly saturated or fluctuate within a few cm of the surface over several days to a week.	0.1	0.1	
	Soil saturated to surface throughout the year.	0.0	0.0	
Direct	Range of water table fluctuation between 75% and 125% of reference standard.	1.0	1.0	
	Range of water table fluctuation between 25% and 75% or >125% of reference standard.	0.5	0.5	
	Range of water table fluctuation between 0% and 25% of reference standard.	0.1	0.1	
	Static water tables or water tables much deeper than reference standard.	0.0	0.0	
	Index of V_{WFT} =			

Calculation of Change in Function (Transfer index of variable to this table)

Conditions	Index of Variable		
	V_{PORE}	V_{WTF}	*Index of Function*: $(V_{PORE} + V_{WTF})/2$
a) Pre-Project/Mitigation			
b) Post-Project/ Mitigation			
Change Due to Project (subtract b from a)			

Synopsis of Subsurface Storage of Water

Definition. Availability of water storage beneath the wetland surface. Storage capacity becomes available as periodic drawdown of the water table or reduction in soil saturation occurs making drained pores available for storage of water.

Effects onsite. Short- and long-term water storage; influences biogeochemical processes in the soil; retains water for establishment and maintenance of biotic communities.

Effects offsite. Surficial groundwater recharge; maintains base flow; maintains seasonal flow distribution.

Description of indicators and variables.

V_{PORE}, ***Soil pore space available for storage.*** Soil texture and drawdown of the water table (creating air-filled pores) are factors that must be considered in scaling this variable. Coarser soil textures (sandy loams and coarser) and water tables that fluctuate within 15 to 30 cm of the surface, yet maintain wetland soil wetness conditions, would have a high potential for subsurface water storage. Comparisons must be made to similar conditions defined by the reference standard.

V_{WTF}, ***Functional water table.*** The water tables of most riverine wetlands undergo drawdowns due to evapotranspiration and drainage, and rises due to precipitation and flood events. Drawdowns combine with pore space to provide potential volume for storage of water below the wetland surface.

$$Index\ of\ Function = (V_{PORE} + V_{WTF})/2$$

Tally Sheet for Moderation of Groundwater Flow or Discharge

Site Location ______________________________

Reference Domain ______________________________

Team ______________________________

Date ______________________________

V_{SUBIN}: Subsurface Flow Into Wetland

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Example of the reference standard determined by regional standard: 1. Seeps present at edge of wetland or 2. Vegetation growing during dormant season or drought (i.e., wet soils support vegetation) or 3. Wetland occurs at toe of slope or 4. Artesian flow (upwelling) on wetland surface.	1.0	1.0	
	Regional standard greatly reduced.	0.5	0.5	
	Regional standard absent with potential for recovery.	0.1	0.1	
	Regional standard absent with no potential for recovery.	0.0	0.0	
Direct	1. Groundwater discharge measured in seeps of springs and discharge from wetland or 2. Positive (upward) groundwater gradient measured by piezometers.	0.0 - 1.0	0.0 - 1.0	
	Index of V_{SUBIN} =			

V_{SUBOUT}: Subsurface Flow From Wetland to Aquifer or Base Flow

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Example of the reference standard determined by regional standard: 1. Sandy soils without underlying impeding layer or 2. Permeable underlying stratigraphy.	1.0	1.0	
	Regional standard greatly reduced.	0.5	0.5	
	Regional standard absent with potential for recovery.	0.1	0.1	
	Regional standard absent with no potential for recovery.	0.0	0.0	
Direct	Negative (downward) groundwater gradient measured by piezometers; score relative to reference standard.	0.0 - 1.0	0.0 - 1.0	
	Index of V_{SUBOUT} =			

Calculation of Change in Function (Transfer indices of variables to this table)

Condition	Indices of Variables		Index of Function: $(V_{SUBIN} + V_{SUBOUT})/2$
	V_{SUBIN}	V_{SUBOUT}	
a) Pre-Project/Mitigation			
b) Post-Project/Mitigation			
Change Due to Project (subtract b from a)			

Synopsis of Moderation of Groundwater Flow or Discharge

Definition. Capacity for wetland to moderate the rate of groundwater flow or discharge from upgradient sources.

Effects onsite. Prolong wetness/saturated soil conditions; extended growing season; moderate soil temperatures.

Effects offsite. Maintains upgradient or upslope groundwater storage, base flow, seasonal flow regimes, surface water temperature.

Description of indicators and variables.

V_{SUBIN}, ***Subsurface flow into the wetland.*** May be indicated by the presence of seeps, springs, or early and/or late season vegetation growth (indication of warmer groundwater seepage to root zone). As inflow to the wetland encounters either low gradients or zones of reduced permeability, hydrodynamics of flow are moderated.

V_{SUBOUT}, ***Subsurface flow from wetland to aquifer or to base flow.*** Presence or absence of underlying horizons or strata that may restrict flow due to lower permeability indicates whether subsurface discharge occurs in the wetland. Strata or horizons of reduced permeability indicate principal flow vectors to lateral discharge points, usually in the stream channel. The absence of restricting permeability horizons indicates that flow may occur unrestricted to the underlying aquifer. Flow may also occur to the stream.

$$Index\ of\ Function = (V_{SUBIN} + V_{SUBOUT})/2$$

Tally Sheet for Nutrient Cycling

Site Location ______________________
Reference Domain ______________________
Team ______________________
Date ______________________

V_{PROD}: Aerial Net Primary Productivity

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Percent cover of all strata (canopy, etc.) between 75% and 125% of reference standard.	1.0	1.0	
	Percent cover as above, but between 25% and 75% or >125% of reference standard.	0.5	0.5	
	Leaf area or living biomass between 0% and 25% of reference standard or the site lacks living biomass due to clearing with potential for recovery.	0.1	0.1	
	No leaf area due to clearing; no potential for recovery.	0.0	0.0	
Direct	Annual litterfall or living biomass accumulation estimated from stand metrics as a linear relationship between reference standard (1.0) and absent (0.0).	0.0 - 1.0	0.0 - 1.0	
	Index of V_{PROD} =			

V_{TURNOV}: Annual Turnover of Detritus

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stocks of detrital and soil organic matter between 75% and 125% of reference standards in terms of snags, down dead woody debris, leaf litter, fermentation and humus layers, and fungal fruiting bodies.	1.0	1.0	
	As above, but between 25% and 75%, or >125% of reference standards.	0.5	0.5	
	As above, but between 0% and 25% of reference standards or stocks of detrital and soil organic matter absent with potential for recovery.	0.1	0.1	
	Area barren; no potential for recovery.	0.0	0.0	
Direct	Turnover of detritus and soil organic matter a linear function between reference standard (1.0) and absent (0.0).	0.0 - 1.0	0.0 - 1.0	
	Index of V_{TURNOV} =			

Calculate Change in Function (Transfer indices of variables to this table)

Condition	Indices of Variables		Index of Function: (the lesser of the two)
	V_{PROD}	V_{TURNOV}	
a) Pre-Project/Mitigation			
b) Post-Project/Mitigation			
Change Due to Project/Mitigation (subtract b from a)			

Synopsis of Nutrient Cycling

Definition. Abiotic and biotic processes that convert nutrients and other elements from one form to another; primarily recycling processes.

Effects onsite. Net effects of recycling are elemental balances between gains through import processes and losses through hydraulic export, efflux to the atmosphere, and long-term retention in persistent biomass and sediments.

Effects offsite. To the extent that nutrients are held onsite by recycling, they will be less susceptible to export downstream. This reduces the level of nutrient loading offsite.

Index of function. Aerial net primary productivity (V_{PROD}) and annual turnover of detritus (V_{TURNOV}) are the variables. These must be scaled to existing reference conditions appropriate for the physiographic region and the wetland's functional class. Index of Function is V_{PROD} or V_{TURNOV}, whichever is lower relative to reference standards.

Description of indicators and variables.

V_{PROD}, ***Aerial net primary productivity.*** Aerial net primary productivity (ANPP) is one of two variables for the function. Aerial net primary productivity is dependent on the development of leaf area, and estimates of leaf are assumed to be roughly indicative of primary productivity. Other components of ANPP have been estimated in some forested wetlands from the relationship between basal area and age for developing stands. It is assumed that biomass is a rough approximation of whether uptake processes are in place. If biomass is absent or reduced relative to the reference standard, the causes may be due to natural or man-made disturbance. Annual litterfall and leaf area index (as determined from interception of incoming solar radiation) are possible indices of ANPP. Litterfall is only one component of ANPP, however, and may be less responsive to stressors than stem growth. Leaf area index is another indicator that ANPP is taking place. It may be estimated by light interception by the canopy relative to the reference standard.

V_{TURNOV}, ***Annual turnover of detritus.*** Standing stocks of detritus are assumed to be proportional to annual turnover. Stocks include snags, down and dead woody debris, the forest floor or "O" horizons of soil (leaf litter, fermentation, and humus layers), and the organic component of mineral soil. Sites equivalent to the reference standard in detrital stocks and soil organic component score 1.0. Detrital stocks that are noticeably reduced score 0.5; if major disturbance has depleted the site of most soil and detrital organic matter, the function receives a 0.1 or zero depending on potential for recovery.

$$\textit{Index of Function} = \textit{If } V_{PROD} > V_{TURNOV}, \textit{ then } V_{TURNOV}; \textit{ otherwise } V_{PROD}$$

Tally Sheet for Removal of Imported Elements and Compounds

Site Location ______________________________
Reference Domain ______________________________
Team ______________________________
Date ______________________________

V_{FREQ}: Frequency of Overbank Flow

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0	1.0	
	As above, but somewhat greater or less than that of reference standard.	0.5	0.5	
	Above indicators absent, but related indicators suggest overbank flow may occur.	0.1	0.1	
	Indicators absent and/or there is evidence of alteration affecting variable.	0.0	0.0	
Direct	Gauge data (1.5) yr return interval similar to reference standard.	1.0	1.0	
	Gauge data (>2 or <1) yr return interval.	0.5	0.5	
	Gauge data show extreme departure from reference standard.	0.1	0.1	
	Gauge data indicate no flooding from overbank flow.	0.0	0.0	
	Index of V_{FREQ} =			

V_{SURFIN}: Surface Inflow to the Wetland

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Any of the following indicators similar to reference standard: 1. Rills on adjacent upland slopes. 2. Lateral tributaries entering floodplain and not connected to the channel.	1.0	1.0	
	Neither of the above indicators similar to reference standards, and either of the above indicators less the reference standard.	0.5	0.5	
	Absence of both of the above indicators.	0.1	0.1	
	Absence of both of the above indicators and hydraulic gradient reversed by regional cone of depression or channelization across wetland and ditches present at toe of slope.	0.0	0.0	
Direct	Use of data from runoff collectors as a continuous variable from reference standard (1.0) to absent (0.0).	0.0-1.0	0.0-1.0	
	Index of V_{SURFIN} =			

V_{SUBIN}: Subsurface Flow Into Wetland

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Example of the reference standard determined by regional standards: 1. Seeps present at edge of wetland or 2. Vegetation growing during dormant season or drought (i.e., wet soils support vegetation) or 3. Wetland occurs at toe of slope or 4. Artesian flow (upwelling) on wetland surface.	1.0	1.0	
	Regional standards greatly reduced.	0.5	0.5	
	Regional standards absent with potential for recovery.	0.1	0.1	
	Regional standards absent with no potential for recovery.	0.0	0.0	
Direct	1. Groundwater discharge measured in seeps or springs and discharge from wetland or 2. Positive (upward) groundwater gradient measured by piezometers and scored relative to reference standard.	0.0-1.0	0.0-1.0	
	Index of V_{SUBIN} =			

V_{MICRO}: Microtopographic Complexity

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual estimate indicates that microtopographic complexity (MC) is >75% and <125% of reference standard.	1.0	1.0	
	Visual assessment confirms MC is somewhat less than reference standard.	0.5	0.5	
	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1	0.1	
	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0	0.0	
Direct	Microtopographic complexity (MC) measured (surveyed) shows MC >75% to 125% of reference standard.	1.0	1.0	
	Measured MC is between 25% and 75% of reference standard.	0.5	0.5	
	Measured MC between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No MC at assessed site or natural substrate replaced by artificial surface; no restoration possible.	0.0	0.0	
	Index of V_{MICRO} =			

V_{MICROB}: Surfaces for Microbial Activity

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Indicators similar to reference standard, i.e., litter layer, humus stratum, woody debris, and floating, submersed, and herbaceous emergents.	1.0	1.0	
	As above, but indicators less than reference standards.	0.5	0.5	
	Indicators absent, with potential for recovery.	0.1	0.1	
	Indicators absent, without potential for recovery.	0.0	0.0	
Direct	Mass of litter layer measured as a continuous variable from reference standard (1.0) to absent (0.0).	0.0-1.0	0.0-1.0	
	Index of V_{MICROB} =			

V_{SORPT}: Sorptive Properties of Soils

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Physical properties of soil similar to the reference standard.	1.0	1.0	
	Soil departs in texture, organic carbon content, and other properties.	0.5	0.5	
	Major departures (e.g., sand to cobbles, clay to sand).	0.1	0.1	
	Surfaces lacking soil or natural substrate (e.g., asphalt, concrete).	0.0	0.0	
Direct	Cation exchange capacity and percent base saturation similar to reference standard.	1.0	1.0	
	As above, but less than reference standards.	0.5	0.5	
	As above, but greatly reduced from reference standards.	0.1	0.1	
	Soil absent; replaced by nonsoil surfaces.	0.0	0.0	
	Index of V_{SORPT} =			

V_{BTREE}: Tree Basal Area

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stage of succession similar to reference standard.	1.0	1.0	
	Stage of succession significantly departs from reference standard.	0.5	0.5	
	Stage of successional at extreme departure from reference standard.	0.1	0.1	
	Stand cleared without potential for recovery.	0.0	0.0	
Direct	Basal area is greater than 75% of reference standard.	1.0	1.0	
	Basal area between 25% and 75% of reference standard.	0.5	0.5	
	Basal area between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No trees present; restoration not possible.	0.0	0.0	
	Index of V_{BTREE} =			

Calculation of Change in Function (Transfer indices of variables to this table)

Condition	Indices of Variables							Index of Function = $\{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN})/3] + [(V_{MICRO} + V_{MICROB} + V_{SORPT})/3] + V_{BTREE})\}/3$
	V_{FREQ}	V_{SURFIN}	V_{SUBIN}	V_{MICRO}	V_{MICROB}	V_{SORPT}	V_{BTREE}	
a) Pre-Project/ Mitigation								
b) Post-Project/ Mitigation								
Change Due to Project (subtract b from a)								

Synopsis of Removal of Elements and Compounds

Definition. The removal of imported nutrients, contaminants, and other elements or compounds.

Effects onsite. Nutrients and contaminants in surface or ground water that come in contact with sediments are either removed from the site or rendered "noncontaminating" because they are broken down into innocuous and biogeochemically inactive forms.

Effects offsite. Chemical constituents removed and concentrated in wetlands, regardless of source, reduce downstream loading.

Description of indicators and variables.

V_{FREQ}, ***Frequency of overbank flow.*** Without flooding from overbank flow, there would be little opportunity for waterborne materials in streams to be removed by biogeochemical processes operating on floodplain wetlands. For an unaltered site that receives flooding at a 2- to 5-year interval, the 2- to 5-year interval would score a 1.0; an annual flooding regime would be inappropriate for that site and would score less than 1.0.

V_{SURFIN}, ***Surface inflow to the wetland.*** When precipitation rates exceed soil infiltration rates, overland flow in uplands adjacent to riverine wetland may be a water source. Indicators include the presence of rill and rearranged litter on the upland leading to the floodplain.

V_{SUBIN}, ***Subsurface flow into the wetland.*** May be indicated by the presence of seeps, springs, or early and/or late-season vegetation growth (indication of warmer groundwater seepage to root zone). As inflow to the wetland encounters either low gradients or zones of reduced permeability, hydrodynamics of flow are moderated.

V_{MICRO}, ***Microtopographic complexity.*** Microtopographic complexity is an expression of the tortuosity of flow pathways. The greater the complexity (roughness), the more the resistance to flow and water will be detained for longer periods of time.

V_{MICROB}, ***Surfaces for microbial activity.*** The primary reason that many chemicals and compounds are removed by wetlands is due to microbial activity. Microbes in aquatic ecosystems tend to be associated with complex surfaces such as leaf litter, humus and soil particles, and plant surfaces.

V_{SORPT}, ***Sorptive properties of soils.*** Physical and chemical removal of dissolved elements and compounds occurs through complexation, precipitation, and other mechanisms of removal. Phosphorus is the best studied.

V_{BTREE}, ***Tree basal area.*** If the plant community of a wetland is accumulating biomass over the long term, through forest development, the capacity to detain elements for longer than 1 year is enhanced because woody parts are recycled (turn over) more slowly than nonwoody parts. Fallen logs and roots that occasionally become buried in wetlands require much longer to recycle than those that decompose above-ground.

$$\textit{Index of Function} = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN})/3] + [(V_{MICRO} + V_{MICROB} + V_{SORPT})/3] + V_{BTREE}\}/3$$

If the vegetation is dominated by short-lived herbaceous species, then V_{BTREE} can be removed without penalty, such that:

$$\textit{Index of Function} = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN})/3] + [(V_{MICRO} + V_{MICROB} + V_{SORPT})/3]\}/2$$

It is assumed that the three groups of variables, water sources, soil properties, and uptake by vegetation, are equally important in maintaining the function at the reference standard.

Tally Sheet for Retention of Particulates

Site Location ______________________________
Reference Domain ______________________________
Team ______________________________
Date ______________________________

V_{FREQ}: Frequency of Overbank Flow

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0	1.0	
	As above, but somewhat greater or less than reference standard.	0.5	0.5	
	Above indicators absent but related indicators suggest overbank flow may occur.	0.1	0.1	
	Above indicators absent and/or there is evidence of alteration affecting variable.	0.0	0.0	
Direct	Gauge data (1.5) yr return interval; similar to reference standard.	1.0	1.0	
	Gauge data (>2 or <1) yr return interval; departure from reference standard.	0.5	0.5	
	Gauge data show extreme departure from reference standard.	0.1	0.1	
	Gauge data indicate no flooding from overbank flow.	0.0	0.0	
	Index of V_{FREQ} =			

V_{SURFIN}: Surface Inflow to the Wetland

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Any of the following indicators similar to reference standard: 1. Rills on adjacent upland slopes. 2. Lateral tributaries entering floodplain and not connected to the channel.	1.0	1.0	
	Both of the above indicators similar to reference standards, and any of the above indicators less than reference standard.	0.5	0.5	
	Absence of both of the above indicators.	0.1	0.1	
	Absence of both of the above indicators, and channelization across wetland prevents sedimentation on wetland surface.	0.0	0.0	
Direct	Use of data from runoff collectors as a continuous variable from reference standard (1.0) to absent (0.0).	0.0-1.0	0.0-1.0	
	Index of V_{SURFIN} =			

V_{HERB}: Herbaceous Plant Density

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Herbaceous plant cover between 75% and 125% that of reference standard.	1.0	1.0	
	Herbaceous plant cover between 25% and 75%, or more than 125% that of reference standard.	0.5	0.5	
	Herbaceous plant cover between 0% and 25% that of reference standard.	0.1	0.1	
	Herbaceous plant cover absent; restoration not possible.	0.0	0.0	
Direct	Herbaceous density, biomass, or cover scaled as a linear function of reference standard ranging from 1.0 to 0.0	1.0	1.0	
	Index of V_{HERB} =			

V_{SHRUB}: Shrub Density

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual estimate of shrubs and saplings indicates site is similar (>75%) to reference standard.	1.0	1.0	
	Visual estimate of shrubs and saplings indicates site is between 25% and 75% that of reference standard.	0.5	0.5	
	Shrubs and saplings sparse or absent relative to reference standard; restoration possible.	0.1	0.1	
	Shrubs and saplings absent; restoration not possible.	0.0	0.0	
Direct	Shrub abundance >75% that of reference standard.	1.0	1.0	
	Shrub abundance between 25% and 75% that of reference standard.	0.5	0.5	
	Shrub abundance between 0% and 25% that of reference standard.	0.1	0.1	
	Shrubs absent; restoration not possible.	0.0	0.0	
	Index of V_{SHRUB} =			

V_{BTREE}: Tree Basal Area

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stage of succession similar to reference standard.	1.0	1.0	
	Stage of succession departs significantly from reference standard.	0.5	0.5	
	Stage of succession at extreme departure from reference standard; restoration possible.	0.1	0.1	
	Stand cleared; no restoration possible.	0.0	0.0	
Direct	Basal area or biomass is greater than 75% of reference standard.	1.0	1.0	
	Basal area or biomass between 25% and 75% of reference standard.	0.5	0.5	
	Basal area or biomass between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No trees are present; restoration not possible.	0.0	0.0	
	Index of V_{BTREE} =			

V_{DTREE}: Tree Density

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stage of succession similar to reference standard.	1.0	1.0	
	Stage of succession departs significantly from reference standard.	0.5	0.5	
	Stage of succession at extreme departure from reference standard; restoration possible.	0.1	0.1	
	Stand cleared; no restoration possible.	0.0	0.0	
Direct	Measured or estimated tree density is between 75% and 125% of reference standard.	1.0	1.0	
	Tree density is between 25% and 75%, or between 125% and 200% of reference standard.	0.5	0.5	
	Tree density is between 0% and 25%, or greater than 200% of reference standard; restoration possible.	0.1	0.1	
	No trees are present; restoration not possible.	0.0	0.0	
	Index of V_{DTREE} =			

V_{MICRO}: Microtopographic Complexity

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual estimate indicates that microtopographic complexity (MC) is >75% and <125% of reference standard.	1.0	1.0	
	Visual assessment confirms MC is somewhat less than reference standard.	0.5	0.5	
	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1	0.1	
	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0	0.0	
Direct	Microtopographic complexity (MC) measured (surveyed) shows MC >75% to <125% of reference standard.	1.0	1.0	
	Measured MC is not between 25% and 75% that of reference standard.	0.5	0.5	
	Measured MC is between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No MC at assessed site or natural substrate replaced by artificial surface; no restoration possible.	0.0	0.0	
	Index of V_{MICRO} =			

V_{CWD}: Coarse Woody Debris

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Volume of CWD is >75% and <125% of reference standard.	1.0	1.0	
	Volume of CWD is between 25% and 75% that of reference standard.	0.5	0.5	
	Volume of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No CWD present; restoration not possible.	0.0	0.0	
Direct	Biomass of CWD is >75% and <125% of reference standards.	1.0	1.0	
	Biomass of CWD is between 25% and 75% that of reference standard.	0.5	0.5	
	Biomass of CWD is between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No CWD present; restoration not possible.	0.0	0.0	
	Index of V_{CWD} =			

V_{SEDIM}: Retained Sediments

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Silt or sediment layering on surfaces or buried root collars or natural levees between 75% and 125% of reference standard.	1.0	1.0	
	As above, but between 25% and 75% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% or >125% of reference standard.	0.1	0.1	
	Hydrologic alterations eliminate variable; restoration not possible.	0.0	0.0	
Direct	Accumulation rates using cesium-137, lead-210, feldspar clay layer, scaled as a linear function from reference standard (1.0) to absent (0.0).	0.0-1.0	0.0-1.0	
	Index of V_{SEDIM} =			

Calculation of Change in Function (Transfer indices of variables to this table)

Conditions	Indices of Variables									Index of Function = $\{[(V_{FREQ} + V_{SURFIN})/2] \times [(V_{HERB} + V_{SHRUB} + V_{BTREE} + V_{DTREE} + V_{MICRO} + V_{CWD})/6]\}^{1/2}$ Option 2: Index = V_{SEDIM}
	V_{FREQ}	V_{SURFIN}	V_{HERB}	V_{SHRUB}	V_{BTREE}	V_{DTREE}	V_{MICRO}	V_{CWD}	V_{SEDIM}	
a) Pre-Project/ Mitigation										
b) Post-Project/ Mitigation										
Change Due to Project (subtract b from a)										

Synopsis of Retention of Particulates

Definition. Deposition and retention of inorganic and organic particulates (>0.45 μm) from the water column, primarily through physical processes.

Effects onsite. Sediment accumulation contributes to the nutrient capital of the ecosystem. Deposition increases surface elevation and changes topographic complexity. Organic matter may also be retained for decomposition, nutrient recycling, and detrital food web support.

Effects offsite. Reduces stream sediment load and entrained woody debris that would otherwise be transported downstream.

Description of indicators and variables.

V_{FREQ}, Frequency of overbank flow. Flooding from overbank flow is the transport mechanism by which sediments from streams enter floodplains. Many of these are simply indicative of recent flooding (silt lines) or may have occurred during an infrequent event (ice scour), and therefore not be particularly helpful in establishing the flooding return interval of a particular site.

V_{SURFIN}, Surface inflow to the wetland. When precipitation rates exceed soil infiltration rates, overland flow in uplands adjacent to riverine wetland may be a water source. Indicators include the presence of rill and rearranged litter on the upland leading to the floodplain.

V_{HERB}, V_{SHRUB}, V_{BTREE}, V_{DTREE}, V_{MICRO}, V_{CWD}, Roughness of surfaces. Frictional force of water passes over surfaces and creates turbulent flow and reduced velocities, both of which are conducive to sediment deposition. Here, three variables are scaled independently. However, Manning's coefficients have been developed for site-specific data to attempt to provide quantitative relationships between roughness and wetland structure.

V_{SEDIM}, Retained sediments. Direct evidence of retained sediments is the best qualitative indicator. Occasionally, layers of leaves will be buried under sediment layers, but such rates of deposition are infrequent in most undisturbed and small watersheds.

$$\begin{aligned} \textit{Index of Function} = {} & \{[(V_{FREQ} + V_{SURFIN})/2] \\ & \times [(V_{HERB} + V_{SHRUB} + V_{BTREE} + V_{DTREE} \\ & + V_{MICRO} + V_{CWD})/6]\}^{1/2} \end{aligned}$$

$$\textit{Option 2: Index} = V_{SEDIM}$$

Tally Sheet for Organic Carbon Export

Site Location ______________________________
Reference Domain ______________________________
Team ______________________________
Date ______________________________

V_{FREQ}: Frequency of Overbank Flow

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0	1.0	
	As above, but somewhat greater or less than reference standard.	0.5	0.5	
	Above indicators absent, but related indicators suggest overbank flow may occur.	0.1	0.1	
	Indicators absent and/or there is evidence of alteration affecting variable; restoration not possible.	0.0	0.0	
Direct	Gauge data (1.5) yr return interval similar to the reference standard.	1.0	1.0	
	Gauge data (>2 or <1) yr return interval.	0.5	0.5	
	Gauge data show extreme departure from reference standard.	0.1	0.1	
	Gauge data indicate no flooding from overbank flow.	0.0	0.0	
	Index of V_{FREQ} =			

V_{SURFIN}: Surface Inflow to the Wetland

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Any of the following indicators similar to reference standard: 1. Rills on adjacent upland slopes. 2. Lateral tributaries entering floodplain and not connected to the channel.	1.0	1.0	
	Neither of the above indicators similar to reference standards, and either of the above indicators less than reference standard.	0.5	0.5	
	Absence of both of the above indicators.	0.1	0.1	
	Absence of both of the above indicators, and hydraulic gradient reversed by regional cone of depression, or channelization across wetland prevents inflow.	0.0	0.0	
Direct	Use of data from runoff collectors as a continuous variable from reference standard (1.0) to absent (0.0).	0.0-1.0	0.0-1.0	
	Index of V_{SURFIN} =			

V_{SUBIN}: Subsurface Flow into Wetland

Method (choose one)	Measure Relative to the Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Example of the reference standard determined by regional standards: 1. Seeps present at edge of wetland or 2. Vegetation growing during dormant season or drought (i.e., wet soils support vegetation) or 3. Wetland occurs at toe of slope or 4. Artesian flow (upwelling) on wetland surface.	1.0	1.0	
	Regional standards greatly reduced.	0.5	0.5	
	Regional standards absent with potential for recovery.	0.1	0.1	
	Regional standards absent with no potential for recovery.	0.0	0.0	
Direct	1. Groundwater discharge measured in seeps of springs and discharge from wetland or 2. Positive (upward) groundwater gradient measured by piezometers and scored relative to reference standards.	0.0-1.0	0.0-1.0	
	Index of V_{SUBIN} =			

$V_{SURFCON}$: Surface Hydraulic Connections with Channel

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual estimates of internal drainage channels present and connected to main channel between 75% and 125% of reference standard.	1.0	1.0	
	As above but between 25% and 75% or >125% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	Internal drainage channels absent or present and blocked from main channel.	0.0	0.0	
Direct	No direct measures.			
	Index of $V_{SURFCON}$ =			

V_{ORGAN}: Organic Matter in Wetland

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual estimates of litter, coarse woody debris, live woody vegetation, live or dead herbaceous plants, organic-rich mineral soils, or histosols at levels between 75% and 125% that of reference standard.	1.0	1.0	
	As above, but between 25% and 75% or >125% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	No organic matter; no potential for recovery.	0.0	0.0	
Direct	Measured standing stocks of live and dead biomass and soil organic matter between 75% and 125% of reference standard.	1.0	1.0	
	As above but between 25% and 75% or >125% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	Standing stocks of live and dead biomass and soil organic matter absent.	0.0	0.0	
	Index of V_{ORGAN} =			

Calculation of Change in Function (Transfer indices of variables to this table)

Condition	Indices of Variables					*Index of Function* = $\{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN} + V_{SURFCON})/4] \times V_{ORGAN}\}^{1/2}$
	V_{FREQ}	V_{SURFIN}	V_{SUBIN}	$V_{SURFCON}$	V_{ORGAN}	
a) Pre-Project/ Mitigation						
b) Post-Project/ Mitigation						
Change Due to Project (subtract b from a)						

Synopsis of Organic Carbon Export

Definition. Export of dissolved and particulate organic carbon from the wetland. Mechanisms include leaching, flushing, displacement, and erosion.

Effects onsite. The removal of organic matter from living biomass, detritus, and soil organic matter contributes to decomposition. Metals may be mobilized by chelation.

Effects offsite. Provides support for aquatic food webs and biogeochemical processing downstream from the wetland.

Description of indicators and variables.

V_{FREQ}, ***Frequency of overbank flow.*** Flooding from overbank flow supplies water to the floodplain surface where long contact times over large surface areas of organic-rich sediments allow organic matter to accumulate in surface waters. Indices are related to flooding frequencies, with the maximum of 1.0 for a site that receives annual flooding because the reference domain falls into that return interval. Indices for other frequencies are lower, and lack of overbank flow receives a zero.

V_{SURFIN}, ***Surface inflow to the wetland.*** When precipitation rates exceed soil infiltration rates, overland flow in uplands adjacent to riverine wetland may be a water source. Indicators include the presence of rill and rearranged litter on the upland leading to the floodplain.

V_{SUBIN}, ***Subsurface flow into the wetland.*** May be indicated by the presence of seeps, springs, or early and/or late-season vegetation growth (indication of warmer groundwater seepage to root zone). As inflow to the wetland encounters either low gradients or zones of reduced permeability, hydrodynamics of flow are moderated.

$V_{SURFCON}$, ***Surface hydraulic connections with channel.*** Internal networks of channels are common features on large riverine floodplains. These channels are conduits for overbank flow during increasing flows, but also act as drainages during the descending limb of the hydrograph. Where natural levees are prominent, as in alluvial river systems, breaks in the levee also indicate this type of flow.

V_{ORGAN}, ***Organic matter in wetland.*** Both live and dead plant materials are capable of contributing to the organic carbon concentration of exported water. A subindex of 1.0 is earned if there is a mix of leaf material, woody debris, and organic carbon content equivalent to the reference standard. A zero would be assigned for a site barren of both detritus and living plants with no potential for recovery.

$$Index\ of\ Function = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN} + V_{SURFCON})/4] \times V_{ORGAN}\}^{1/2}$$

Tally Sheet for Maintain Characteristic Plant Community

Site Location ______________________________

Reference Domain ______________________________

Team ______________________________

Date ______________________________

V_{COMP}: Species Composition for Tree, Shrub, and Ground Cover Strata

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Published lists of dominant species in each stratum that show presence of same species as reference standard.	1.0	1.0	
	Site devoid of vegetation or no species shared with reference standard.	0.0	0.0	
Direct	Three of the dominant species in each of the 4 vegetation strata match 3 of the 4 dominants in equivalent strata of reference standard.	1.0	1.0	
	As above, but ground cover does not meet reference standard.	0.75	0.75	
	As above, but ground cover and saplings do not meet reference standard.	0.5	0.5	
	As above, but only tree stratum meets reference standard.	0.25	0.25	
	None of the strata meets reference standard.	0.0	0.0	
	Index of V_{COMP} =			

V_{REGEN}: Seedlings/Saplings and/or Clonal Shoots

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Published lists or unpublished lists that are verified and show same species composition as reference standard.	1.0	1.0	
	Site devoid of vegetation or no species shared.	0.0	0.0	
Direct	Ratio of seedling/sapling species to canopy species is within 75% of the ratio for the reference standard.	1.0	1.0	
	As above, but between 25% and 75% of the ratio of the reference standard.	0.5	0.5	
	As above, but between 0% and 25% of the ratio of the reference standard.	0.1	0.1	
	Seedlings/saplings and/or clonal shoots are absent or share no species with reference standard sites.	0.0	0.0	
	Index of V_{REGEN} =			

V_{CANOPY}: Canopy Cover

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Remote or other indirect methods not recommended.			
Direct	Measure of canopy cover is >75% of reference standard.	1.0	1.0	
	As above, but between 25% and 75% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	Canopy cover is absent.	0.0	0.0	
	Index of V_{CANOPY} =			

V_{DTREE}: Tree Density

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stage of succession similar to reference standard.	1.0	1.0	
	Stage of succession departs significantly from reference standard.	0.5	0.5	
	Stage of succession at extreme departure from reference standard; restoration possible.	0.1	0.1	
	Stand cleared; no restoration possible.	0.0	0.0	
Direct	Measured or estimated tree density is between 75% and 125% of reference standard.	1.0	1.0	
	Tree density is between 25% and 75%, or between 125% and 200%, of reference standard.	0.5	0.5	
	Tree density is between 0% and 25%, or greater than 200%, of reference standard; restoration possible.	0.1	0.1	
	No trees are present; restoration not possible.	0.0	0.0	
	Index of V_{DTREE} =			

V_{BTREE}: Tree Basal Area

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Stage of succession similar to reference standard.	1.0	1.0	
	Stage of succession departs significantly from reference standard.	0.5	0.5	
	Stage of successional at extreme departure from reference standard; restoration possible.	0.1	0.1	
	Stand cleared; no restoration possible.	0.0	0.0	
Direct	Basal area or biomass is greater than 75% of reference standard.	1.0	1.0	
	Basal area or biomass between 25% and 75% that of reference standard.	0.5	0.5	
	Basal area or biomass between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No trees present; restoration not possible.	0.0	0.0	
	Index of V_{BTREE} =			

Calculate Change in Function (Transfer indices of variables to this table)

Conditions	Indices of Variables					*Index of Function* = $[V_{COMP} + V_{REGEN} + V_{CANOPY} + (V_{DTREE} + V_{BTREE})/2]/4$
	V_{COMP}	V_{REGEN}	V_{CANOPY}	V_{DTREE}	V_{BTREE}	
a) Pre-Project/Mitigation						
b) Post-Project/Mitigation						
Change Due to Project (subtract b from a)						

Synopsis of Maintain Characteristic Plant Community

Definition. Species composition and physical characteristics of living plant biomass. The emphasis is on the dynamics and structure of the plant community as revealed by the dominant species of trees, shrubs, seedlings, saplings, and ground cover, and by the physical characteristics of vegetation.

Effects onsite. Converts solar radiation and carbon dioxide into complex organic compounds that provide energy to drive food webs. Provides seeds for regeneration. Provides habitat for nesting, resting, refuge, and escape cover for animals. Creates microclimatic conditions that support completion of life histories of plants and animals. Creates roughness that reduces velocity of floodwaters. Provides organic matter for soil development and soil-related nutrient cycling processes. Creates both long- and short-term habitat for resident or migratory animals.

Effects offsite. Source of propagules to maintain species composition and/or structure of adjacent areas and to supply propagules for colonization of nearby degraded systems. Provides food and cover for animals from adjacent ecosystems. Provides corridors (migratory pathways) between habitats, enhances species diversity and ecosystem stability, and provides habitat and food for migratory and resident animals. Supports primary and secondary production in associated aquatic habitats. Contributes leaf litter and coarse woody debris habitat for animals in associated aquatic habitats (Bilby 1981).

Description of indicators and variables.

V_{COMP}, ***Species composition for tree, sapling, shrub, and ground cover strata***. The reference standard is a complete species list for the appropriate reference site. If the assessment site contains >75 percent of the species in the reference site, a score of 1.0 is given. Similarities of >25 and <75 percent score 0.5, and values between 0 and 25 percent score a 0.1. If there are no species in common, 0.0 is given. Indirect measures should not be used unless the data source can be verified and the data are recent. For all of the variables used to evaluate this function, indirect measures yield scores that are similar to those given for direct measures only if the data are verified.

V_{REGEN}, ***Seedlings/saplings and/or clonal shoots***. If a direct measure shows that the ratio of sapling and seedling species to the canopy species is within 75 percent of the reference standard (a mature forest), the assessment site has a high probability of being stable and an index of 1.0 is given for the variable. Scores of 0.5 and 0.1, respectively, are given if the measure shows 25 to 75 percent and 1 to 25 percent similarity in proportion to the ratio of species found in reference standard sites. If the species composition of seedlings or saplings has no similarities with the reference site, or if the site is devoid of vegetation, an index of 0.0 is given. If information is available only from an indirect measure such as a species list that has been published or obtained from an unpublished source, a score of 1.0 is given only if it is possible to verify the information. Plant communities of marshes can be compared also, but without the need to specify strata.

V_{CANOPY}, ***Canopy cover***. If the percent cover in the assessment site is >75 percent of the value established from the reference standard sites, a score of 1.0 is given. Index scores of 0.5 and 0.1 are given when the assessment site and reference standards show 25 to 75 percent and 0 to 25 percent similarity, respectively. A 0.0 is given when there is no tree layer. Indirect measures of percent cover should not be used unless it is impossible to make a direct measure. Recent aerial photographs, taken during the growing season, can be used to provide an indirect measure but they should be used with great caution as changes may have occurred at the assessment site between the time the evaluation is made and the time that the photographs were taken. If data from the indirect measure are verified during a visit to the assessment site, scores can be given using the same ranges as used for direct measures.

V_{DTREE}, ***Tree density***. If tree density at the assessment site is 75 to 125 percent of reference standard, it may be assumed that the site is stable, and a score of 1.0 is given. A score of 0.5 is assigned if the range is either 25 to 75 percent or 125 to 200 percent. Densities beyond the foregoing ranges (i.e., higher or lower) are assigned 0.1. The absence of tree species receives a 0.0. Indirect measures of density and basal area should not be used unless it is impossible to obtain a direct measure. The only acceptable indirect measure should be published data or data that have not been published but can be verified. The same intervals may be used for published or verified data.

V_{BTREE}, ***Tree basal area***. Because basal area of trees can be estimated accurately with angle gauges and prisms, indirect measures do not offer any advantage over direct ones. Therefore, measurements above the reference standard receive a 1.0, while all other measures below that level are assigned an index value proportional to the reference standard.

$$\textit{Index of Function} = [V_{COMP} + V_{REGEN} + V_{CANOPY} + (V_{DTREE} + V_{BTREE})/2]/4$$

Tally Sheet For Characteristic Detrital Biomass

Site Location ____________________
Reference Domain ____________________
Team ____________________
Date ____________________

V_{SNAGS}: Density of Standing Dead Trees (Snags)

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	No suitable measure available.			
Direct	Density >75% of reference standard.	1.0	1.0	
	Density between 25% and 75% of reference standard.	0.5	0.5	
	Density between 0% and 25% of reference standard.	0.1	0.1	
	No standing dead trees; restoration not possible.	0.0	0.0	
	Index of V_{SNAGS} =			

V_{CWD}: Coarse Woody Debris

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Volume of CWD is >75% and <125% of reference standard.	1.0	1.0	
	Volume of CWD is between 25% and 75% that of reference standard.	0.5	0.5	
	Volume of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No CWD present; restoration not possible.	0.0	0.0	
Direct	Biomass of CWD is >75% and <125% of reference standard.	1.0	1.0	
	Biomass of CWD is between 25% and 75% that of reference standard.	0.5	0.5	
	Biomass of CWD is between 0% and 25% that of reference standard; restoration possible.	0.1	0.1	
	No CWD present; restoration not possible.	0.0	0.0	
	Index of V_{CWD} =			

V_{LOGS}: Logs in Several Stages of Decomposition

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	No suitable indirect measure.			
Direct	Greater than 75% of the range of log decay classes relative to reference standard.	1.0	1.0	
	Between 25% and 75% of log decay classes relative to reference standard.	0.5	0.5	
	Logs are only one decay class regardless of average diameter and length.	0.1	0.1	
	Site contains no logs.	0.0	0.0	
	Index of V_{LOGS} =			

V_{FWD}: Fine Woody Debris (Accumulating in Active Channels, and/or Microtopographic Depressions)

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	No suitable indirect measure.			
Direct	Cover of fine woody debris >75% of reference standard.	1.0	1.0	
	Cover of fine woody debris between 25% and 75% of reference standard.	0.5	0.5	
	Cover of fine woody debris between 0% and 25% of reference standard.	0.1	0.1	
	No fine woody debris present.	0.0	0.0	
	Index of V_{FWD} =			

Calculate Change in Function (Transfer Indices of Variables to This Table)

Conditions	Indices of Variables				*Index of Function* = $\{V_{SNAGS} + [(V_{CWD} + V_{LOGS})/2] + V_{FWD}\}/3$
	V_{SNAGS}	V_{CWD}	V_{LOGS}	V_{FWD}	
a) Pre-Project/Mitigation					
b) Post-Project/Mitigation					
				Change Due to Project (subtract b from a)	

Synopsis of Maintain Characteristic Detrital Biomass

Definition. The processes of production, accumulation, and dispersal of dead plant biomass of all sizes. Sources may be onsite or upslope and upgradient. Emphasis is on the amount and distribution of standing and fallen woody debris.

Effects onsite. Provides primary resources for supporting detrital-based food chains, which support the major nutrient-related processes (cycling, export, import) within the wetland. Provides important resting, feeding, hiding, and nesting sites for animals of higher trophic levels. Provides surface roughness that decreases velocity of floodwaters. Retains, detains, and provides opportunities for in situ processing of particulates. Primarily responsible for organic composition of soil.

Effects offsite. Provides sources of dissolved and particulate organic matter and nutrients for downstream ecosystems. Contributes to reduction in downstream peak discharges and delayed downstream delivery of peak discharges. Contributes to downstream water quality through particulate retention and detention.

Description of indicators and variables.

V_{SNAGS}, ***Density of standing dead trees (snags)***. A direct measure of the number (density) of standing dead trees at the assessment site is compared to the reference standard. If the density is >75 percent of the reference standard, the variable score is 1.0. If the density is <75 percent but >25 percent, the index score is 0.5. A score of 0.1 is given when the density of standing dead trees at the assessment site is between 1 and 25 percent of the reference standard. A score of 0.0 is given when there are no standing dead trees at the assessment site. For an indirect measure, a variable score of 0.5 is given when recent and verified aerial photography, taken during the growing season, shows that the assessment site has >75 percent of the density of standing dead trees found under reference standards. An indirect measure between 0 and 75 percent of the reference standard is 0.1, and 0.0 is given when no standing dead trees are shown on the aerial photographs.

V_{CWD}, ***Coarse woody debris***. If the density of fallen logs at the assessment site is >75 percent of the reference standard a score of 1.0 is given. Comparisons that are <75 percent are scored as 0.5 or 0.1 depending on whether the assessment site has >25 to <75 percent or >0 to <25 percent of the density relative to the reference standard, respectively. If the assessment site has no coarse woody debris on the soil surface, a variable score of 0.0 is given. The only appropriate indirect measure would be information compiled from recent aerial photographs, taken during the leafless season. There is no appropriate indirect measure if the site is dominated by evergreen trees. A variable score of 0.5 is given if the aerial photographs show that the assessment site has >75 percent of the density of fallen logs compared to reference standards. Values <75 percent are scored 0.1 and a score of 0.0 is given when no fallen logs are shown on aerial photographs.

***V_{LOGS}*, Logs in several stages of decomposition**. A direct measure is the abundance (e.g., common, rare, absent) of logs in five classes of decomposition. If the assessment site has approximately the same number (>75 percent) of log decay classes and relative abundance of logs in each class, a variable score of 1.0 is given. If the assessment site has fewer log decay classes and as little as 25 percent of the reference standard, a score of 0.5 is given. If the assessment site contains logs in only one of the decay classes and if the reference standard has logs in four or more of the classes, a score of 0.1 is given. If the assessment site contains no logs, a score of zero is given. There is no suitable indirect measure for this variable.

***V_{FWD}*, Fine woody debris (accumulating in active channels and side channels)**. When the amount of organic matter accumulated in channels in the assessment site is approximately similar to the amount found in the reference site(s), a score of 1.0 is given. If the amount and distribution of accumulated debris is medium compared to the reference site(s), an index score of 0.5 is given. When the assessment site contains little accumulated organic matter (a low amount) relative to reference standards, a score of 0.1 is given. When there is very little or no accumulated organic matter compared to reference standard, the variable score is 0.0. There is no suitable indirect measure for this variable.

Index of function. The abundance of standing (V_{SNAGS}) and downed (V_{LOGS}) logs, the decay stages of the logs (V_{CWD}), and the abundance of piles of accumulated organic matter (V_{FWD}) are the variables used to assess the detritus function. All variables must be scaled to existing reference standards appropriate for the physiographic region and the wetland's functional class.

$$Index\ of\ Function = \{V_{SNAGS} + [(V_{CWD} + V_{LOGS})/2] + V_{FWD}\}/3$$

Tally Sheet for Maintain Spatial Structure of Habitat

Site Location ______________________________
Reference Domain ___________________________
Team ______________________________________
Date ______________________________________

V_{SNAGS}: Density of Standing Dead Trees (Snags)

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	In selected forest types, aerial photos may be used to estimate density.			
Direct	Density $\geq$75% of reference standard.	1.0	1.0	
	Density between 25% and 75% of reference standard.	0.5	0.5	
	Density between 0% and 25% of reference standard.	0.1	0.1	
	No standing dead trees.	0.0	0.0	
	Index of V_{SNAGS} =			

V_{MATUR}: Abundance of Very Mature Trees

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	No suitable measures available.			
Direct	Density of very mature trees >75% of reference standard.	1.0	1.0	
	Density of very mature trees between 25% and 75% of reference standard.	0.5	0.5	
	Density of very mature trees between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No very mature trees present; no potential for restoration.	0.0	0.0	
	Index of V_{MATUR} =			

V_{STRATA}: Number and Attributes of Vertical Strata of Vegetation

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Complexity of canopy (number of strata) shown on recent aerial photos taken in leaf season, with field calibration, similar to reference standard.	1.0	1.0	
	As above, but less than reference standard.	0.5	0.5	
	No canopy; restoration possible.	0.1	0.1	
	No canopy; restoration not possible.	0.0	0.0	
Direct	1. Number of vertical strata, 2. Density or cover of plants in each stratum, or 3. Some composite index of above: Is >75% of reference standard.	1.0	1.0	
	As above, but between 25% and 75% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	Vertical strata missing.	0.0	0.0	
	Index of V_{STRATA} =			

V_{PATCH}: Vegetation Patchiness

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Texture of canopy shown on recent aerial photos taken in leaf season, field calibrated, similar to reference standard.	1.0	1.0	
	As above, but less than reference standard.	0.5	0.5	
	Recent aerial photos show no tree canopy.	0.0	0.0	
Direct	Appropriate measure of patchiness >75% and <125% of reference standard.	1.0	1.0	
	As above, but between 25% and 75% or >125% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	No canopy present.	0.0	0.0	
	Index of V_{PATCH} =			

V_{GAPS}: Gaps in Forest

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Recent aerial photographs taken during leaf-out season show gaps in the tree canopy similar in number, size, and abundance to reference standard.	1.0	1.0	
	As above, but less than reference standard.	0.5	0.5	
	Methods above indicate no gaps in tree canopy.	0.0	0.0	
Direct	Number, distribution, or size frequency of gaps in the forest canopy 75% to 125% of reference standard.	1.0	1.0	
	As above, but between 25% and 75% or >125% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	No canopy gaps present.	0.0	0.0	
	Index of V_{GAPS} =			

Calculate Change in Function (Transfer Indices of Variables to This Table)

Conditions	Indices of Variables					Index of Function = $(V_{SNAGS} + V_{MATUR} + V_{STRATA} + V_{PATCH} + V_{GAPS})/5$
	V_{SNAGS}	V_{MATUR}	V_{STRATA}	V_{PATCH}	V_{GAPS}	
a) Pre Project/Mitigation						
b) Post Project/Mitigation						
Change Due to Project (subtract b from a)						

Synopsis of Maintain Spatial Structure of Habitat

Definition. The capacity of a wetland to support animal populations and guilds by providing heterogeneous habitats.

Effects onsite. Provides potential feeding, resting, and nesting sites for vertebrates and invertebrates. Regulates and moderates fluctuations in temperature. Provides habitat heterogeneity to support a diverse assemblage of organisms. Affects all ecosystem processes.

Effects offsite. Provides habitat heterogeneity to landscape, provides habitat for wide-ranging and migratory animals, provides a corridor for gene flow between separated populations, and allows excess progeny to exploit new areas.

Description of indicators and variables.

V_{SNAGS} , ***Density of standing dead trees (snags)***. Mature forests and forests subjected to periodic disturbances on the order of decades or longer usually possess standing dead trees (snags). The importance of snags to woodpecker foraging is well established (they feed on insects that are decomposing the snag). In addition, limbs of large snags provide resting, perching, feeding, and nesting sites for large birds, particularly raptors. Other avian predators use snags for resting, feeding, searching for prey, and drying-out. Neotropical songbirds, waterfowl, and woodpeckers nest within snag cavities. Mammals and reptiles use snags for feeding, nesting, and hunting. Density determinations should focus on the larger size classes of snags (with respect to reference standards), because large snags provide the widest range of potential habitats for use by animals.

V_{MATUR} , ***Abundance of very mature trees***. Standing and mature or dying trees provide nesting habitat for a variety of animal species, including invertebrates, birds, reptiles, amphibians, and mammals. The density of very mature tress must be calibrated to some old-growth reference standard sites. Other indirect measures, for example determining the density or species richness of cavity nesting birds, are too time consuming and more logistically limited than making a direct count of cavities. Index scores are determined as in V_{SNAGS} above.

V_{STRATA} , ***Number and attributes of vertical strata of vegetation***. Mature forested wetlands are usually vertically stratified. The number of strata in mature riverine forests generally ranges between three and seven in temperate North America. Because forest organisms exhibit a remarkable fidelity to a particular stratum, differences in structure between sites likely represent differences in animal composition between sites as well. In fact, more spatially stratified communities often contain more species. Vertical stratification must be measured directly and compared with the reference standard when assessing a site.

V_{PATCH}, ***Vegetation patchiness***. Heterogeneity in distribution and abundance (patchiness) of organisms is inherent at all scales in every natural ecosystem. Any measure of ecosystem attributes must consider the appropriate scale and sample size in which to measure those attributes in order to understand ecosystem processes (competition, trophic interactions, energy flow, habitat structure). Wetlands are no exception. Habitat heterogeneity occurs across different spatial scales for different plant life forms (canopy, shrub, herbaceous, etc.) and across different hydrogeomorphic classes. Patchiness of vegetation affects the types and abundances of trophic interactions, energy flow, and competitive interactions of animals. These processes in turn affect animal populations. The scale at which patchiness is measured and evaluated determines the reliability and usefulness of measurements. For example, shrubs and trees may not be uniformly distributed across a forested wetland landscape. Each habitat type supports a different assemblage of bird species, and the combined species richness (for birds) of both habitats is greater than the richness of either area evaluated separately.

V_{GAPS}, ***Canopy gaps***. Canopy gaps often indicate forest maturity, particularly in assessing unaltered sites. Mature sites are normally used to represent the best reference standard because they generally support the highest biodiversity. However, canopy gaps may reflect both natural and anthropogenic disturbances and should be used with caution when applying the variable to the Maintain Spatial Structure of Habitat Function. As with all variables, using the appropriate reference domain is critical in determining the variable condition of an assessment site.

$$\textit{Index of Function} = (V_{SNAGS} + V_{MATUR} + V_{STRATA} + V_{PATCH} + V_{GAPS})/5$$

Tally Sheet for Maintain Interspersion and Connectivity

Site Location ______________________________
Reference Domain ______________________________
Team ______________________________
Date ______________________________

V_{FREQ}: Frequency of Overbank Flow

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	At least one of the following: aerial photos showing flooding, water marks, silt lines, alternating layers of leaves and fine sediment, ice scars, drift and/or wrack lines, sediment scour, sediment deposition, directionally bent vegetation similar to reference standard.	1.0	1.0	
	As above, but somewhat greater or less than reference standard.	0.5	0.5	
	Above indicators absent but related indicators suggest overbank flow may occur.	0.1	0.1	
	Indicators absent and/or alteration has eliminated variable.	0.0	0.0	
Direct	Gauge data (1.5) yr return interval similar to reference standard.	1.0	1.0	
	Gauge data show (>2 or <1) yr return interval.	0.5	0.5	
	Gauge data show extreme departure from reference standard.	0.1	0.1	
	Gauge data indicate no flooding from overbank flow.	0.0	0.0	
	Index of V_{FREQ} =			

V_{DURAT}: Duration of Overbank Flow

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Duration of connection-related indicators only, and similar to reference standard.	1.0	1.0	
	Any indicators, i.e., aerial photos showing continuity of duration, flooding tolerance of tree species, etc., showing continuity of flooding as less than reference standard.	0.5	0.5	
	Any indicators showing greatly reduced duration relative to reference standard.	0.1	0.1	
	Flooding is absent.	0.0	0.0	
Direct	Gauge data (x-y) yr show duration of connection between 75% and 125% of reference standard.	1.0	1.0	
	As above, but between 25% and 75%, or >125% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	Gauge data indicate no overbank flow.	0.0	0.0	
	Index of V_{DURAT} =			

V_{MICRO}: Microtopographic Complexity

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual estimate indicates that microtopographic complexity (MC) is between 75% and 125% of reference standard.	1.0	1.0	
	Visual assessment confirms MC is present, but somewhat less than reference standard.	0.5	0.5	
	Visual assessment indicates MC is much less than reference standard; restoration possible.	0.1	0.1	
	Visual assessment indicates MC is virtually absent or natural substrate replaced by artificial surface; restoration not possible.	0.0	0.0	
Direct	Microtopographic complexity (MC) measured (surveyed) shows MC >75% to <125% of reference standard.	1.0	1.0	
	As above, but MC of site is between 25% and 75% that of reference standard.	0.5	0.5	
	Measured MC between 0% and 25% of reference standard; restoration possible.	0.1	0.1	
	No MC at assessed site or natural substrate replaced by artificial surface; restoration not possible.	0.0	0.0	
	Index of V_{MICRO} =			

$V_{SURFCON}$: Surface Hydraulic Connections with Channel

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Number of surface connections 75% to 125% of reference standard.	1.0	1.0	
	Number of surface connections 25% to 50% of reference standard.	0.5	0.5	
	Number of surface connections 0% to 25% of reference standard.	0.1	0.1	
	No surface connections due to obstructions or alterations.	0.0	0.0	
Direct	Use of data from runoff collectors as a continuous variable from reference standard (1.0) to absent (0.0).			
	Index of $V_{SURFCON}$ =			

V_{SUBCON}: Subsurface Hydraulic Connections with Channel

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Seeps, springs, upwellings similar to reference standard.	1.0	1.0	
	Excessive fine sediment supply sufficient to block subsurface connections.	0.5	0.5	
	Stream channel and floodplain highly altered with minimal connections.	0.1	0.1	
	No possible subsurface connections exist because of alterations.	0.0	0.0	
Direct	Direct measures not practical. Tracer and dye methods are required.			
	Index of V_{SUBCON} =			

V_{CONTIG}: Contiguous Vegetation Cover and/or Corridors Between Wetland and Upland, Between Channels, and Between Upstream and Downstream Areas

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Recent aerial photographs taken during leaf season show abundant vegetation and vegetated corridors connecting mosaics of habitat types similar to reference standard.	1.0	1.0	
	Recent aerial photographs taken during the leaf season show lower abundance of vegetative connections than reference standard.	0.5	0.5	
	Lack of continuous vegetation connections with potential for recovery.	0.1	0.1	
	Lack of continuous vegetation connections with no potential for recovery.	0.0	0.0	
Direct	Continuity >75% of reference standard.	1.0	1.0	
	As above, but between 25% and 75% of reference standard.	0.5	0.5	
	As above, but between 0% and 25% of reference standard.	0.1	0.1	
	Assessment site fragmented and isolated from channels and adjacent uplands and upstream-downstream wetland areas.	0.0	0.0	
	Index of V_{CONTIG} =			

Calculate Change in Function (Transfer indices of variables to this table)

Conditions	Indices of Variables						*Index of Function* = $(V_{FREQ} + V_{DURAT} + V_{MICRO} + V_{SURFCON} + V_{SUBCON} + V_{CONTIG})/6$
	V_{FREQ}	V_{DURAT}	V_{MICRO}	$V_{SURFCON}$	V_{SUBCON}	V_{CONTIG}	
a) Pre Project/Mitigation							
b) Post Project/Mitigation							
Change Due to Project/Mitigation (subtract b from a)							

Synopsis of Maintain Interspersion and Connectivity

Definition. The capacity of the wetland to permit aquatic organisms to enter and leave the wetland via permanent or ephemeral surface channels, overbank flow, or unconfined hyporheic gravel aquifers. The capacity of a wetland to permit access of terrestrial or aerial organisms to contiguous areas of food and cover.

Effects onsite. Provides habitat diversity. Contributes to secondary production and complex trophic interactions. Provides access to and from wetland for reproduction, feeding, rearing, and cover. Contributes to completion of life cycles and dispersal between habitats.

Effects offsite. Provides corridors for wide-ranging or migratory species. Provides refugia for plants and animals. Provides conduits for dispersal of plants and animals to other areas.

Description of indicators and variables.

V_{FREQ}, ***Frequency of overbank flow***. The frequency of overbank flow is a critical component of the character of a particular riverine wetland. Such flooding is often an integral part of affording access to the wetland by anadromous or adfluvial fishes that use floodplain habitats, especially wetlands, to complete portions of their life histories (e.g., spawning and rearing). The temporal periodicity and magnitude of flooding may have direct bearing on year-class strengths among vertebrates. Likewise, overbank flow and connectivity between the main channel and floodplain wetlands affect the dispersal of plant propagules or plant parts. Thus, flooding and connectivity are critical components of site-specific structure and function. Overbank flow is best quantified by hydrographic data.

V_{DURAT}, ***Duration of overbank flow***. The duration of overbank flow is determined by both the discharge upriver and the volume of water that gets dissipated across and temporarily stored on adjacent floodplains during floods. Thus, the duration of overbank flow is affected by the size of the floodplain and the hydraulic connectivity between the main channel and floodplain wetlands. The duration of flooding is important in permitting organisms sufficient time to access wetlands for spawning and feeding, and in allowing some species to complete important life-history developmental stages. Longer periods of flooding may also aid in the dispersal of some plants. However, it should be kept in mind that what benefits one set of organisms may be a detriment to others. Every species of plants and animals requires some restricted range of flooding duration to maintain an optimal population size.

V_{MICRO}, ***Microtopographic complexity***. Microtopographic relief is an important factor contributing to the interspersion of habitat types and connections between river and floodplain wetlands. Elevated structures (for example, hummocks) and low areas (for example, channels and small depressions) direct the flow of water through wetlands and affect direction and duration of flows. Wetlands with a mosaic of interspersed habitat types provide conditions suitable for a higher diversity of plant and animal species than do wetlands with uniform topography. A direct measure of surface roughness is acquired by performing a survey of microtopography (using an auto-level, laser-total survey, etc.) within a well-designed suite of transects intersecting the wetland.

$V_{SURFCON}$ and V_{SUBCON}, Hydraulic connections among main and side channels, surface, and subsurface. Multiple hydraulic connections between a river and the wetlands on its floodplain strongly indicate a high heterogeneity of habitats (and hence relatively high species diversity), interspersion among habitat types, and the potential for complex trophic interactions.

V_{CONTIG}, Contiguous vegetation cover and/or corridors between wetland and upland, between channels, and between upstream-downstream areas. Continuity of vegetation, connectivity of specific vegetation types, the presence and scope of corridors between upland and wetland habitats, and corridors between wetlands all have direct bearing on the movement and behavior of animals that use wetlands. Assessment of this variable is region-specific, and must be placed in the context of the animal species that are known to utilize these connections.

$$Index\ of\ Function = (V_{FREQ} + V_{DURAT} + V_{MICRO} + V_{SURFCON} + V_{SUBCON} + V_{CONTIG})/6$$

Tally Sheet for Maintain Distribution and Abundance of Invertebrates

Site Location ______________________________
Reference Domain ______________________________
Team ______________________________
Date ______________________________

V_{SINVT}: Distribution and Abundance of Invertebrates in Soil

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Tunnels, shells, casts, holes, etc., in soil similar to reference standard.	1.0	1.0	
	As above, but much less than reference standard.	0.5	0.5	
	No evidence of items above, but with potential for habitat recovery.	0.1	0.1	
	No evidence of items above and no potential for recovery of habitat.	0.0	0.0	
Direct	Similarity index for species composition and abundance of soil invertebrates >75% of reference standard.	1.0	1.0	
	Similarity index between 25% and 75% of reference standard.	0.5	0.5	
	Similarity index 0% to 25% of reference standard.	0.1	0.1	
	No soil invertebrates or evidence of soil invertebrates found.	0.0	0.0	
	Index of V_{SINVT} =			

V_{LINVT}: Distribution and Abundance of Invertebrates in Leaf Litter and Coarse Woody Debris

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual assessment of galleries in logs and twigs, tunnels in wood, shells, casts, trails, holes, etc., similar to reference standard.	1.0	1.0	
	As above, but much less than reference standard.	0.5	0.5	
	Absence of above conditions, but with potential for recovery.	0.1	0.1	
	Absence of above conditions, but potential for recovery.	0.0	0.0	
Direct	Similarity index for species composition and abundance of invertebrates ≥75% of reference standard.	1.0	1.0	
	Similarity index between 25% and 75% of reference standard.	0.5	0.5	
	Similarity index between 0% to 25% of reference standard.	0.1	0.1	
	No invertebrates or evidence of invertebrates found in leaf litter or coarse woody debris.	0.0	0.0	
	Index of V_{LINVT} =			

V_{AQINVT}: Distribution and Abundance of Invertebrates in Aquatic Habitats

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Presence of suitable aquatic habitats (microdepressions, seeps, etc.) and evidence of shell fragments, exudate, etc., similar to reference standard. Measures may be developed that can be quantified.	1.0	1.0	
	As above, but indicators much less than reference standard.	0.5	0.5	
	No evidence of items above, but with potential for habitat recovery.	0.1	0.1	
	No evidence of suitable aquatic habitats present and no potential for habitat recovery.	0.0	0.0	
Direct	Similarity index for species composition and abundance or regional indicator or keystone species ≥75% of reference standard.	1.0	1.0	
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	0.5	0.5	
	Similarity index for species composition and abundance 0% to 25% of reference standard.	0.1	0.1	
	No invertebrates or evidence of invertebrates found in aquatic habitats.	0.0	0.0	
	Index of V_{AQINVT} =			

Calculate Change in Function (Transfer indices of variables to this table)

Conditions	Indices of Variables			Index of Function = $(V_{SINVT} + V_{LINVT} + V_{AQINVT})/3$
	V_{SINVT}	V_{LINVT}	V_{AQINVT}	
a) Pre Project/Mitigation				
b) Post Project/Mitigation				
Change Due to Project/Mitigation (subtract b from a)				

Synopsis of Maintain Distribution and Abundance of Invertebrates

Definition. The capacity of the wetland to maintain the density and spatial distribution of invertebrates (aquatic, semi-aquatic, and terrestrial).

Effects onsite. Provides food (energy) to predators, aerates soil and coarse woody debris by building tunnels, in breaking down coarse woody debris increases availability of organic matter for nutrient cycling microbes, and disperses seeds within site.

Effects offsite. Provides food (energy) for wide-ranging carnivores/insectivores, etc. Transports seeds and propagules for germination elsewhere.

Description of indicators and variables.

V_{SINVT}, ***Distribution and abundance invertebrates in soil***. Measurements of invertebrate density and species richness must be compared with the reference standard. A direct measure of invertebrate species richness and abundance at the assessment site is best obtained by any of several standard sampling techniques. Rapid assessment is possible in the field by people familiar with the dominant taxa. Similarity can be determined by comparing density, species richness, or some index of similarity (see any ecology text for a discussion of such measures).

V_{LINVT}, ***Distribution and abundance of invertebrates in leaf litter and coarse woody debris***. Determining invertebrate activity in coarse woody debris is best determined by direct measurements. Similarity can be determined by comparing density, species richness, or some index of similarity (see any ecology text for a discussion of such measures). The reference standard is a species richness and abundance (or some similarity measure) commensurate with the reference standard.

V_{AQINT}, ***Distribution and abundance of invertebrates in aquatic habitats (e.g., microdepressions, seeps, side channels)***. Direct measures of aquatic invertebrates should be made using standard sampling techniques. Rapid assessment procedures for sampling aquatic invertebrate, identification, and enumeration are fairly well established, but these methods require specialized training and expertise.

$$Index\ of\ Function = (V_{SINVT} + V_{LINVT} + V_{AQINVT})/3$$

Tally Sheet for Maintain Distribution and Abundance of Vertebrates

Site Location ______________________________

Reference Domain ______________________________

Team ______________________________

Date ______________________________

V_{FISH}: Distribution and Abundance of Resident and Migratory Fish

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Surrogate measurements (e.g., egg masses, larval and fry stages, and adults) similar to reference standard.	1.0	1.0	
	Above indicators much less than reference standard.	0.5	0.5	
	No evidence of indicators above, but potential for habitat recovery.	0.1	0.1	
	No evidence of indicators above and no potential for habitat recovery.	0.0	0.0	
Direct	Similarity index for species composition and abundance ≥75% of reference standard.	1.0	1.0	
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	0.5	0.5	
	Similarity index for species composition and abundance between 0% and 25% of reference standard.	0.1	0.1	
	No fish or evidence of fish found.	0.0	0.0	
	Index of V_{FISH} =			

V_{HERP}: Distribution and Abundance of Herptiles

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Surrogate measures (e.g., egg masses, tracks, calls, larval stages, skins, skeletons) similar to reference standard.	1.0	1.0	
	Evidence of above indicators, but less than reference standard.	0.5	0.5	
	No evidence of above indicators, but potential for habitat recovery.	0.1	0.1	
	No evidence of above indicators and no potential for habitat recovery.	0.0	0.0	
Direct	Similarity index for species composition and abundance >75% of reference standard.	1.0	1.0	
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	0.5	0.5	
	Similarity index for species composition and abundance between 0% and 25% of reference standard.	0.1	0.1	
	No herptiles or evidence of herptiles found.	0.0	0.0	
	Index of V_{HERP} =			

V_{BIRD}: Distribution and Abundance of Resident and Migratory Birds

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Surrogate measurements (e.g., nests, tracks, calls, feathers, skeletons) similar to reference standard.	1.0	1.0	
	Evidence of above indicators, but less than reference standard.	0.5	0.5	
	No evidence of above indicators, but potential for recovery of habitat.	0.1	0.1	
	No visual evidence of above indicators and no potential for recovery of habitat.	0.0	0.0	
Direct	Similarity index for species composition and abundance ≥75% of reference standard.	1.0	1.0	
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	0.5	0.5	
	Similarity index for species composition and abundance between 0% and 25% of reference standard.	0.1	0.1	
	No birds or evidence of birds found.	0.0	0.0	
	Index of V_{BIRD} =			

V_{MAMM}: Distribution and Abundance of Permanent and Seasonally Resident Mammals

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Visual evidence of mammals (e.g., trails, scat, kills, presence of prey species, burrows, browsed plants) similar to reference standard.	1.0	1.0	
	As above, but less than reference standard.	0.5	0.5	
	No visual evidence of mammal indicators, but potential for recovery of mammal habitat.	0.1	0.1	
	No visual evidence of mammal indicators, but no potential for recovery of mammal habitat.	0.0	0.0	
Direct	Similarity index for species composition and abundance ≥75% of reference standard.	1.0	1.0	
	Similarity index for species composition and abundance between 25% and 75% of reference standard.	0.5	0.5	
	Similarity index for species composition and abundance between 0% and 25% of reference standard.	0.1	0.1	
	No mammals or evidence of mammals found and no potential for recovery of habitat to reference standard.	0.0	0.0	
	Index of V_{MAMM} =			

V_{BEAV}: Beaver Abundance

Method (choose one)	Measure Relative to Reference Standard	Pre Project/ Mitigation	Post Project/ Mitigation	Comments and Notes
Indirect	Surrogate measurements (e.g., recent aerial photographs, presence of active and abandoned lodges and dams, cut and chewed plants, scat, trails) similar to reference standard.	1.0	1.0	
	As above, but indicators less than reference standard.	0.5	0.5	
	No evidence of above indicators, but potential for recovery of habitat exists.	0.1	0.1	
	No evidence of above indicators and no potential for recovery of beaver habitat.	0.0	0.0	
Direct	Abundance ≥75% of reference standard.	1.0	1.0	
	Abundance between 25% and 75% of reference standard.	0.5	0.5	
	Abundance between 0% and 25% of reference standard.	0.1	0.1	
	No beaver or evidence of beaver found.	0.0	0.0	
	Index of V_{BEAV} =			

Calculate Change in Function (Transfer indices of variables to this table)

Conditions	Indices of Variables					Index of Function = $(V_{FISH} + V_{HERP} + V_{BIRD} + V_{MAMM} + V_{BEAV})/5$*
	V_{FISH}	V_{HERP}	V_{BIRD}	V_{MAMM}	V_{BEAV}	
a) Pre Project/Mitigation						
b) Post Project/Mitigation						
Change Due to Project/Mitigation (subtract b from a)						

* V_{BEAV} is omitted without penalty if beaver ponds are not considered part of the reference domain.

Synopsis of Maintain Distribution and Abundance of Vertebrates

Definition. The capacity of the wetland to maintain the density and spatial distribution of vertebrates-aquatic, semi-aquatic, and terrestrial. Vertebrates utilize wetlands for food, cover, resting, reproduction, etc.

Effects onsite. Disperse seeds throughout the site, pollinate flowers (bats), aerate the soil and coarse woody debris with tunnels, and alter hydroperiod and light regime (beavers, muskrats).

Effects offsite. Disperse seeds between sites, pollinate flowers (bats), provide food (energy) for predators, and alter hydroperiod and light regime (beavers, muskrats).

Description of indicators and variables.

V_{FISH}, ***Distribution and abundance of resident and migratory resident fish.*** Fish are particularly sensitive to severed connections between a river and its floodplain wetlands. Migratory fish are also sensitive to alterations of in-seasonal hydrologic regimes because many migratory species have evolved to exploit an annual flooding pattern that allows them access to adjoining wetlands for spawning. Fish are relatively well studied in North America, and the scientific literature contains much information on how to measure relative abundance, determine species richness, and calculate similarity indices. The fish density/richness function must be examined in context of reference standards, hydrogeomorphic class, and regional variation.

V_{HERP}, ***Distribution and abundance of herptiles.*** Although herptiles are not as well studied as some other vertebrate groups (particularly birds and fishes), there are still many direct measurement (quantitative) techniques available in the scientific literature for estimating population size or comparing sites, including direct counts, tag/recapture methods, and encounters per unit time.

V_{BIRD}, ***Distribution and abundance of resident and migratory birds.*** The abundance and species richness of birds is closely related to habitat complexity because birds have evolved to fill most available terrestrial niches. In addition, because birds are the best studied group of vertebrates, the scientific literature is replete with information on how to measure relative abundance, determine species richness, and calculate similarity indices.

V_{MAMM}, ***Diversity and abundance of permanent and seasonally resident mammals.*** Mammals are relatively well studied, and there is abundant scientific literature on appropriate censusing techniques (mark/recapture, visual counts, etc.). Wide-ranging mammals (e.g., deer and bear) use wetlands as riparian corridors for foraging, cover, rest, and water. In arid regions, riparian zones are several degrees cooler than surrounding uplands, and mammals often cool off and rest in such areas during midday.

V_{BEAV}, ***Abundance of beaver.*** Beaver effects are manifest through virtually all of the other wetland functions, from dynamics of surface water storage to nutrient cycling to characteristics of the plant community. Beaver activity can be measured in various ways, but direct observation and individual counts provide the best empirical basis for assessment.

Index of Function

With beaver ponds.

$$\text{Index of Function} = (V_{FISH} + V_{HERP} + V_{BIRD} + V_{MAMM} + V_{BEAV})/5$$

Without beaver ponds.

$$\text{Index of Function} = (V_{FISH} + V_{HERP} + V_{BIRD} + B_{MAMM})/4$$

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13. ABSTRACT *(Maximum 200 words)*

The report outlines an approach for assessing wetland functions in the 404 Regulatory Program as well as other regulatory, planning, and management situations. The approach includes a development and application phase. In the development phase, wetlands are classified into regional subclasses based on hydrogeomorphic factors. A functional profile is developed to describe the characteristics of the regional subclass, identify the functions that are most likely to be performed, and discuss the characteristics that influence how those functions are performed. Reference wetlands are selected to represent the range of variability exhibited by the regional subclass in the selected reference domain, and assessment models are constructed and calibrated by an interdisciplinary team based on reference standards and data from reference wetlands. Reference standards are the conditions exhibited by the undisturbed, or least disturbed, wetlands and landscapes in the reference domain. The functional indices resulting from the assessment models provide a measure of the capacity of a wetland to perform functions relative to other wetlands in the regional subclass. The application phase of the approach, or assessment procedure, includes the characterization of the wetland, assessing its functions, analyzing the results of the assessment, and applying them to a specific project. The assessment procedure can be used to compare project alternatives, determine the impacts of a proposed project,

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avoid and minimize impacts, determine mitigation requirements or success, as well as other applications requiring the assessment of wetland functions.

This document is for use by a team of individuals who adapt information in this guidebook to riverine wetlands in specific physiographic regions. By adapting from the generalities of the riverine class to specific regional riverine subclasses, such as high-gradient streams of the glaciated northeastern United States, the procedure can be made responsive to the specific conditions found there. For example, separation of high-gradient from low-gradient streams may be necessary to reduce the amount of variation indicators to make the assessment more sensitive to detecting impacts.

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